WASTE MANAGEMENT PAPER 26F

LANDFILL CO-DISPOSAL

DRAFT FOR EXTERNAL CONSULTATION

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SUMMARY

This document provides guidance on good practice for the waste management industry. It sets out the factors to be considered by a Waste Regulation Authority in the licensing and control of landfills used for co-disposal.

It replaces guidance given previously in Waste Management Paper 26 (1986), and supplements advice on specific wastes, given in other individual Waste Management Papers (WMPs). Statutory guidance on the licensing process itself is in WMP 4.

The guidance contained in this WMP will be periodically reviewed and up-dated. It should be read in conjunction with the other WMPs in the 26 series:

WMP 26A	Landfill Completion
WMP 26B	Landfill Design
WMP 26C	Landfill Operations
WMP 26D	Landfill Monitoring
WMP 26E	Landfill Restoration

In this paper

- **Chapter 1** is an introduction describing the current role of co-disposal in the UK and the developments which have led to the need for up-dated guidance.
- **Chapter 2** defines co-disposal, describes the principles of how it works, and states the conditions necessary for it to be acceptable.
- **Chapter 3** describes the site characteristics necessary for co-disposal, including containment and hydraulic criteria.
- **Chapter 4** discusses the criteria for determining whether co-disposal is an acceptable option for particular wastes.
- **Chapter 5** stipulates how the maximum acceptable loading rates should be determined for particular wastes.
- **Chapter 6** discusses the acceptance arrangements which should be used, including prior assessment of wastes, checks on arrival at the site, and record-keeping of wastes received.
- **Chapter 7** describes operational methods for solid and liquid co-disposal.
- **Chapter 8** addresses various aspects of leachate management including water balance calculations, recirculation, monitoring and treatment or disposal.

- **Chapter 9** describes special considerations for landfill completion arising at co-disposal sites.
- **Appendix A** presents a brief technical overview of the capabilities of co-disposal, based on research to date, and identifies areas where current knowledge is still incomplete.
- **Appendix B** presents a draft leaching test protocol for the assessment of solid waste.
- **Appendix C** presents a draft protocol for an anaerobic bioassay test (ABT) for waste containing List I organic compounds.
- **Appendix D** presents a check list for use when preparing site licence conditions.
- **Appendix E** contains a classification system for chemical components of Special wastes, to be used for record-keeping and reporting on waste inputs.
- **Appendix F** considers special health and safety aspects arising at co-disposal sites.
- **Appendix G** contains schematic illustrations of the calculation of flow through mineral liners and of hydraulic retention time within landfills.

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October 1994

Chapter 1

Introduction

Application of this document

1.1 This document provides technical guidance on the practice of co-disposal. It applies primarily to those wastes covered by the Special Waste Regulations 1980[1].

1.2 In future it will apply to special waste as defined in successor regulations: that will include all wastes covered by the Hazardous Wastes Directive[2]. The guidance should also be applied to the landfilling of any waste listed in table 4.1 of this document.

The UK position on co-disposal

1.3 The co-disposal of selected industrial wastes, including some special wastes, with municipal or similar wastes, has been practised in the UK for many years. The Department supports its continued use, provided that adequate control is applied to site location, engineering, operation and waste inputs, through appropriate licence conditions and site management.

1.4 Co-disposal is not suitable for all industrial or special wastes, many of which should be disposed of by incineration or should be treated. The purpose of this document is to present information and guidance to the waste management industry in general, to assist Waste Regulation Authorities to set licence conditions which provide the necessary degree of control, and to raise operational standards.

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[1] SI 1980 No.1709

[2] 91/689/EEC

1.5 UK recognition of co-disposal as an acceptable and distinctive type of landfill differs from current policy in many other European countries. This arises partly from differences in terminology and partly from differences in practice.

- There has historically been no agreement about what is meant by hazardous wastes.[3]
- Consequently the true extent of co-disposal across the Union has been hard to establish.[4]
- Nevertheless, the range and quantity of industrial wastes disposed of in municipal waste landfills in the UK exceeds that in most other Member States.
- Dedicated hazardous waste landfills are preferred in other European countries but are very uncommon in the UK. The Department of the Environment does not, however, wish to encourage an increase in the number of landfills receiving only special wastes.

The current role of co-disposal in the UK

Co-disposal in perspective

1.6 In the UK many treatment and disposal options are available for special wastes. Co-disposal of solid and liquid industrial wastes, together with biodegradable solid wastes, is one of these options.

- Co-disposal is used for a very high proportion of the UK's solid and sludge residues from industrial processes and from waste treatment plants, and for about half of the aqueous wastes and pumpable sludges.
- Physical-chemical pre-treatment, incineration, and solvent recovery are also used to a large extent: many wastes for which co-disposal would be technically unsuitable are treated by these methods. Pre-treatment is currently used for approximately half the UK arisings of aqueous wastes and pumpable sludges; it typically consists of oil/water separation, acid/alkali neutralization, heavy metal precipitation, and solids removal, followed by discharge of liquid effluent to sewer.
- Flammable wastes are nearly always incinerated.

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[3] Many municipal landfills in other Member States of the EU dispose of industrial wastes: their technique would in the UK be called co-disposal. Some of these wastes would in the UK be defined as special waste; but, although this definition implemented and EC directive, other EC member states took different approaches.

[4] Wastes currently not seen as hazardous in some countries may in the future be included on the definitive list of hazardous waste currently being drawn up under Directive 91/689/EEC.

Waste quantities

1.7 Total UK arisings of special wastes are shown in table 1.1, together with the arisings of other controlled wastes all or some of which are routinely landfilled.

Table 1.1 Annual UK controlled-waste arisings
[from *The UK Environment* 1992]

Waste source	**Arisings Mt/a**	**Percentage of total**
Special - solid - liquid/pumpable sludge	2.7 1.3	1.6 0.8
Household	20	11.6
Commercial	16	9.3
Non-hazardous industrial	68	39.5
Demolition and construction	32	18.6
Sewage sludge (wet weight)	32	18.6
TOTAL	**172**	**100.0**

1.8 A high proportion of the ~2.7 Mt/a of solid special waste is co-disposed. At the landfills practising co-disposal the special wastes typically comprise 5 to 20% of the total waste inputs.

1.9 Very few landfills in the UK are licensed to receive only special wastes, although some landfills at waste producers' premises receive only special wastes, usually comprising a small number of waste types. The quantity of solid waste for which co-disposal may be appropriate is expected to increase, as a result of increasing pre-treatment of liquid wastes and increasing quantities of residues from incineration of domestic waste and sewage sludge.

Number of licensed facilities

1.10 The approximate number of landfills at which co-disposal is currently licensed is shown in table 1.2, together with numbers of other types of facilities, for comparison.

Table 1.2 Approximate numbers of licensed waste management facilities in the UK

Approximate number	Description
5,500	Active waste disposal licences; includes many in-house facilities e.g. lagoons, sludge-drying beds, scrap-yards etc., as well as incinerators, treatment plants and transfer stations.
3,490	**Landfill sites of all types of which:**
~ 1,420	Receive only inert wastes;
~ 2,070	Receive some combination of domestic, commercial and industrial wastes. Of these:
~ 360	Are licensed for co-disposal of biodegradable and special industrial wastes.
~ 50	Receive significant quantities (> 1,000t/a) of liquid industrial waste for co-disposal with methanogenic solid wastes.
~ 30	Merchant physical-chemical pre-treatment plants.
~ 4	Merchant industrial waste incinerators.

Liquid wastes

1.11 Approximately 50 landfills receive 1000 t/a or more of aqueous liquid industrial waste. A similar number receive smaller inputs of largely non-hazardous wastes in tankers, such as

- gulley emptyings
- cess-pit contents
- bentonite muds from drilling or construction works
- clay slurries from pottery manufacture.

The quantity of aqueous liquid waste co-disposed was approximately 500,000 t/a in 1989, the most recent date for which national data are available. The number of sites has decreased since then.

1.12 The distribution among the sites in 1989 indicates that liquid co-disposal is concentrated at a relatively small number of major sites. The majority received less than 5,000 t/a. Typically this would amount to between 1% and 5% of the input tonnage at each site, and to less than 10% of the effective rainfall falling on the site.

- At some major liquid co-disposal sites, liquid waste inputs may range from 25-100% of effective rainfall inputs, and from 10-50% of total waste inputs. At these sites, control of volume tends to be based on the capacity of active leachate management systems.

1.13 Merchant pre-treatment plants handle a similar volume of aqueous liquid wastes to that which is co-disposed. The majority handle more than 10,000 t/a, while the largest is thought to receive about 100,000 t/a.

- The volume of liquids being co-disposed has generally been falling in recent years; the volume being pre-treated has risen. Several new pre-treatment plants have been opened and more are being developed; two of the largest liquid co-disposal operations have recently incorporated pre-treatment of wastes, prior to co-disposal of the liquid effluent.

The volume of liquid waste which is incinerated at merchant special waste incinerators is probably about 80,000 t/a. Commercial solvent recovery plants probably handle about 200,000 t/a of waste liquids.

1.14 A significant proportion of liquid waste arisings is disposed of at in-house sites that include pre-treatment, incineration, landfills, lagoons and sludge drying beds. The aggregate quantity is not known.

1.15 Some liquid or sludge wastes are suitable for more than one disposal route.

- A significant proportion of aqueous wastes could **either** be sent for pre-treatment to remove solids, followed by discharge of liquid effluent to sewer, **or** be co-disposed directly under controlled conditions.
- A small proportion of aqueous wastes containing several per cent of soluble organic compounds, could be incinerated, co-disposed or subjected to physical-chemical pre-treatment.
- Some drummed sludge residues from distillation processes, which are difficult to classify as solid or liquid are landfilled in locally significant quantities but could potentially be incinerated.

There is always a solid, non-incinerable residue which has to be landfilled.

Evolution of co-disposal

The need for research and controls

1.16 At the beginning of the 1970s there were few specific controls over the disposal of industrial wastes in the UK, in common with many other countries. There was little knowledge of how wastes were being disposed of, or of their environmental effects. Several dumping incidents brought this unsatisfactory situation to the attention of the public. New legislation was enacted, and a research programme launched. The results of research, and parallel developments in legislation and government guidance, influenced the subsequent evolution of co-disposal during the 1970s and 1980s.

A developing legislative background

1.17 Legislation enacted during the 1970s provided the framework for effective regulation.

- The Deposit of Poisonous Wastes Act 1972 (subsequently replaced by the Special Waste Regulations, 1980) introduced a system of compulsory prior notification of any transport of difficult wastes. This began to generate national data on the production, movement and disposal locations of a very high proportion of the UK's industrial wastes.
- The Control of Pollution Act 1974 created the Waste Disposal Authorities and introduced a system of site licensing. The licensing of existing landfills was largely completed by the late 1970s. The system remains in force but was enhanced and superseded in 1994 by the licensing provisions of the Environmental Protection Act 1990.

Preliminary research output

1.18 Co-disposal research began in the UK in 1973, with a comprehensive 4-year programme of laboratory and field studies into the behaviour of hazardous wastes in landfills. The programme was funded by the Department of the Environment (DoE) and undertaken jointly by the Water Research Centre, AEA Harwell and the British Geological Survey. The results of these studies were published in 1978 in the Brown Book (DoE, 1978).

1.19 Further research continued during the late 1970s, throughout the 1980s and into the 1990s.

1.20 In 1989 a major technical review of co-disposal and of relevant research was undertaken for the DoE (Knox, 1989). It collated and interpreted the accumulated large body of work; recommended areas needing further research; and demonstrated the efficacy of co-disposal for certain types of industrial waste.

Improvements to regulatory guidance

1.21 From 1976 onwards Waste Management Papers (WMPs) were published, and up-dated, on various aspects of waste management. Working groups were organized by DoE to

- pool information on waste arisings and on disposal experience
- consider the results of the research programme
- highlight areas of uncertainty, where the research programme could usefully undertake experimental work
- assist the Department of the Environment in the production of Waste Management Papers.

Improvements in operational practices

1.22 The combination of legislation, regulation, dissemination of research knowledge, and the publication of WMPs has resulted in the gradual raising of operational standards: the regulatory medium is the setting and enforcement of site licence conditions. There has been a steady decrease in the range of wastes allowed to mix, and a progressive improvement in operational practices.

The need for new guidance

1.23 The Department last published guidance on co-disposal in WMP 26 (DoE, 1986). Significant developments since then have led to the need for revised guidance.

- The Department's technical review (Knox, 1989) defined more clearly
    - ► the capabilities, limitations and operational requirements of co-disposal
    - ► the optimum conditions for a co-disposal landfill to be operated as a reactor.

  Its main findings are given in appendix A of this document.
- There is now a greater emphasis on groundwater protection. This is articulated in the NRA's *Policy and Practice for the Protection of Groundwater* (1992). Its implications for the location and engineering of co-disposal landfills are discussed in chapter 3.
- The need to contribute to the development of the European Directive on the Landfill of Waste created a requirement for a more formalised and detailed approach to controlling co-disposal than that contained in WMP 26 (DoE, 1986).
- The change in site licensing arrangements in May 1994[5] emphasised the need to consider long term liabilities from landfills. Government policy on sustainable development is that waste should be disposed of in such a way that significant pollution control burdens will not be passed on to future generations. The implications of this policy for landfilling in general are discussed in WMP 26A (Completion) and WMP 26C (Operations). Specific implications for co-disposal are discussed in chapters 2 (Principles), 4 (Acceptability of Wastes), 7 (disposal methods) and 9 (Completion).

Relationship with other Waste Management Papers

1.24 This document is concerned with those aspects of design, operations, licensing and control which are specific to co-disposal and it will be necessary to refer to other WMPs for more general guidance. Where relevant, cross-reference is made in the text to the individual Waste Management Papers in the 26 series, listed below:

WMP 26A	Landfill Completion
WMP 26B	Landfill Design
WMP 26C	Landfill Operations
WMP 26D	Landfill Monitoring
WMP 26E	Landfill Restoration

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[5] under the Environmental Protection Act 1990

Future developments likely to influence co-disposal

1.25 This document mentions legislation, standards and other guidance documents that are currently under development. Some changes may be necessary when these are eventually published. They include

- the landfill directive, which may prescribe minimum standards for liners and may place additional restrictions on co-disposal
- the development of a hazardous waste list, under the Hazardous Waste Directive. This could restrict co-disposal of certain waste types under the terms of the landfill directive
- the list, under the Hazardous Waste Directive, will become part of the revised UK Special Waste Regulations. Based on a wider range of properties than the existing regulations, it may lead to a greater number of wastes being classed as special
- the preparation of a standard waste classification scheme suitable for placing record-keeping on a nationally consistent basis
- the development of a risk assessment model for assessing the risk to groundwater from proposed landfills
- the refinement and evaluation of draft UK protocols for leaching tests and anaerobic bioassay tests for wastes being considered for co-disposal
- the development of European standards by CEN (European Centre for Standards), for waste characterization purposes, principally concerning full characterization, acceptance testing and on-site verification.

1.26 On-going research sponsored by the Department may lead to a need to modify this guidance.

Chapter 2

Principles of co-disposal

2.1 This chapter defines co-disposal and its objectives, describes the principles on which it is based, and states the conditions necessary for it to be acceptable and successful.

Definition, objectives and benefits

2.2 Co-disposal is the disposal, in landfills, of a restricted range of industrial wastes (including some special wastes) together with decomposing municipal waste or similar degradable wastes, in such a way that the industrial wastes gradually undergo a form of treatment.

- The aim is to reach a stable state in which the site is unlikely to cause pollution of the environment or harm to human health: that is, a state where active leachate and gas management are no longer needed.

2.3 The effect of co-disposal is that a significant proportion of the UK's special wastes may be disposed of in a manner which would not create long-term liabilities any more severe than those which would arise for municipal waste alone.

- The alternative approach is to dispose of special wastes in landfills receiving no other waste types. It is more likely to create sites that
  - will take longer to reach completion
  - may, in the interim, produce leachates which are harder to treat than those from co-disposal sites.

2.4 For some wastes, co-disposal is considered to represent the best practicable environmental option (BPEO). These are primarily inorganic solid wastes and some aqueous liquid wastes containing

- acids
- heavy metals
- degradable organics
- low concentrations of other readily attenuated components.

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2.5 The Department's policy is that all controlled wastes should be disposed of in a manner that, because it minimises the pollution control burdens we leave behind for future generations, is compatible with the concept of sustainable development.

- This requires

  either pre-treatment of wastes, before they are landfilled, to a quality which will not cause pollution

  or management of landfills themselves as reactors to transform wastes into a non-polluting form.

To achieve this objective for co-disposal, the landfill must operate as a biological reactor. Any soluble pollutants must be

- leached out of the waste, and
- degraded, attenuated or treated in the landfill or externally as part of the leachate management system.

By minimising the period during which the landfill represents a potential source of pollution, the risk of groundwater contamination is greatly reduced in the event of long-term containment failure.

Technical basis for co-disposal

Fundamental principles

2.6 In a decomposing refuse mass there are many mechanisms - physical, chemical and biological - which are similar to those used regularly in treatment plants, and which can immobilise or degrade components of many industrial wastes.

2.7 The objective of co-disposal is to make use of these mechanisms, in a controlled manner, so that

- the landfill remains dominated by the decomposition of municipal or similarly biodegradable wastes, with no inhibition of normal breakdown processes
- there is no effect on leachate quality which would make its treatment or disposal any more difficult or its environmental impact more severe
- there are no unacceptable hazards to operators, regulators, visitors or to site neighbours;
- restoration, after-care and after-use are not significantly hampered, completion is not delayed and long-term liability is not significantly increased.

The landfill as a bioreactor

2.8 Methanogenic municipal waste provides a medium in which

- organic compounds in the municipal waste are being metabolised, from the solid phase through to CH_4 and CO_2 [6]
- a strongly reducing aqueous chemical environment, very similar to anaerobic digesters, with low Eh and near-neutral pH, is maintained in a buffered, steady state by on-going degradation processes
- the solid matrix is extremely heterogeneous, both physically and chemically.

2.9 Landfills may be considered to behave as stationary fixed-film reactors (SFFRs): their hydraulic régimes combine saturated and unsaturated conditions, downflow, lateral flow, single pass and recycle modes.

- Some sites may be predominantly of one configuration, but many display all the above characteristics.

Mean hydraulic retention time (HRT) is often several years and thus very much longer than in conventional reactors. The extent of mixing is usually poorly characterised and may be very variable, with the possibility of short-circuiting in some circumstances.

Research and practical evidence

2.10 The ability of decomposing refuse to degrade and immobilise some components of industrial wastes has been demonstrated repeatedly.

- The research that has demonstrated this capability is summarized in appendix A. It describes the capabilities and limitations of decomposing refuse as a reactive medium, and the site characteristics necessary for landfills to act as efficient reactors.

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[6] The metabolic rates range up to 60g C/m^3.d (based upon gas production data); but rates of ~10g C/m^3.d are more typical. Sewage works digesters typically operate at rates of 500-1500g C/m^3.d.

Requirements for acceptable co-disposal

Site design and operational considerations

2.11 Co-disposal uses the refuse mass as a reactor and relies upon three main principles to achieve its objectives:

- **containment**, so that waste components and leachate are retained in the landfill long enough to ensure that the necessary biological, physical and chemical reactions take place
- **leachate management**, to optimise the performance of the landfill as a bio-reactor. Particularly for solid wastes, leachate is the medium which brings about intimate contact between industrial waste components and the decomposing refuse. Leaching of the solid wastes is essential
- **control of waste inputs**, so that only those waste types which are amenable to co-disposal treatment are allowed into sites, and acceptable loading rates are not exceeded.

Compatibility with sustainable development

2.12 The general criterion for landfill completion, as defined in WMP 26A, is that the condition of the land is unlikely to cause pollution of the environment or harm to human health. To meet this criterion, the co-disposal landfill must be designed, operated and controlled as a flushing reactor through which the passage of moisture is actively engineered, rather than simply as a long-term repository.

- ► This distinguishes it from the dry tomb approach for landfilling special waste residues: in that technique, leachate production is minimised by excluding all moisture from the landfill.

2.13 The flushing reactor concept has important implications for licence conditions[7]. In a reactor landfill, leachate production, leachate management and the leaching process are central to the processing of the wastes: licence conditions must reflect this.

- ► The considerations resemble those that apply to the sustainable landfilling of untreated municipal wastes.
- ► The co-disposal site may, however, present added complexity. The varying inputs of industrial wastes, and some current operational methods, can create a much more heterogeneous waste mass than at a municipal waste landfill.

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[7] For the licensing process and the construction of licence conditions, see WMP 4.

2.14 Licence conditions and operational techniques must avoid the detrimental effects of excessive heterogeneity. In particular, they should deal with

- the need for thorough leaching of the industrial wastes
- the difficulties that may arise in achieving this if wastes are not evenly distributed during infilling.

2.15 For all the foregoing reasons, licence conditions must be thoroughly considered at the outset. The WRA should, even then, take account of the desirability of reviewing licence conditions against accumulating data from the site and increasing experience in co-dosposal.

Chapter 3

Site requirements

Introduction

3.1 This chapter considers the factors that make a site suitable for

- the provision of bio-reactor conditions favourable to co-disposal
- the protection of the aquatic environment from contamination.

3.2 They may be divided into

- **intrinsic** characteristics of the site, determined by factors such as the location, local soil type(s), geology, hydrogeology and climate.

- **engineered** and **operational** characteristics, including the size, type of containment measures, the design of leachate and landfill gas collection/control systems, monitoring and leak detection facilities and site operation procedures (size of cells, rates of infill, co-disposal techniques, compaction, intermediate and final capping procedures etc.).

3.3 The factors outlined above also apply to landfills licensed for purposes other than co-disposal, but the emphasis placed on them may usually be greater for co-disposal.

Influence of intrinsic site characteristics

3.4 The primary considerations are the geology and location of the site. A site may lie on strata with high enough permeability and storage coefficients to form an aquifer, or on the low permeability materials that the NRA define as non-aquifers. In non-aquifer zones, the element of the environment mainly at risk may be the surface waters.

3.5 Protection of the external environment may require the containment and controlled removal of leachate to protect water resources from the escape of potentially polluting liquids, and to prevent landfill gas migration.

Groundwater protection: roles of the NRA and RPAs

Scotland

3.6 Responsibilities that in England fall to the NRA are borne in Scotland by the River Purification Authorities (RPAs). The RPAs have, in general, adopted the broad principles of the NRA's groundwater protection policy described below.

3.7 However, the RPAs are working towards publishing a policy document of their own. It will reflect the threats to groundwater quality that are particularly important in Scotland; and it will, like the NRA policy, emphasise the importance of risk assessment that is site-specific.

The NRA

3.8 The concept of Groundwater Vulnerability forms a cornerstone of the NRA's *Policy and Practice for the Protection of Groundwater* (NRA, 1992).

3.9 The NRA has divided groundwater resources into Major and Minor Aquifers. Other areas are classed as Non-Aquifers.

- Major Aquifers comprise extensive, high permeability formations that may show significant intergranular or fracture porosity (for example the Cretaceous chalk), and can support large abstractions for water supply.
- Minor Aquifers include both superficial deposits and rock formations that are of lower permeability and/or extent than Major Aquifers; they may nevertheless be important in providing local water supplies and in supplying base flow to rivers. Typical examples would be river gravels and the Millstone Grit.

Where protection of surface water resources is required, the NRA does not differentiate between Major Aquifers, Minor Aquifers, and Non-Aquifer zones.

3.10 The NRA groundwater protection policy extends to all aquifers, whether they are currently being used for water supply or not[8]. Current guidance is that

> The same criteria should be applied even when the aquifer is not currently in use, except where an aquifer is permanently unusable. Exact interpretation in individual cases would be a matter for the judgement of the competent authority concerned - in consultation with the NRA as appropriate - **but the protection of groundwater resources should be a prime consideration.**

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[8] Direction of 13 July 1992 issued by the Department of the Environment, the Ministry of Agriculture Fisheries and Food and the Welsh Office to the National rivers Authority. See also the Directive on the Protection of Groundwater Against Pollution Caused by Certain Dangerous Substances (80/68/EEC).

3.11 If a landfill may represent a threat to existing sources of water supply (boreholes and springs, principally those for public supply), the NRA will seek to impose additional protection requirements. It has specified three Source Protection Zones on the basis of estimated groundwater travel time to the source.

3.12 When considering groundwater protection, the NRA does not recognise a co-disposal landfill as belonging to a separate class. It includes them with other types of high pollution potential landfills: those accepting domestic, commercial and industrial waste either individually or on a co-disposal basis. The criteria applied by the NRA are summarized in table 3.1.

Table 3.1 NRA acceptability criteria for co-disposal landfills
Source: National Rivers Authority 1992

A. SOURCE PROTECTION		
INNER ZONE (50-day travel time)	OUTER ZONE (400-day travel time)	CATCHMENT ZONE
Not acceptable	Not acceptable	Only acceptable with engineered containment and operational safeguards

B. RESOURCE PROTECTION		
MAJOR AQUIFER	MINOR AQUIFER	NON-AQUIFER
Only acceptable with engineered containment and operational safeguards	Only acceptable with engineered containment and operational safeguards	Only acceptable with adequate operational safeguards. Engineering measures may be necessary in order to protect surface waters

Notes:
1. Operational safeguards include site management, leachate control and monitoring.
2. Mono-disposal of special wastes is acceptable to the NRA only in Non-Aquifer areas.

Site-specific assessment

3.13 The criteria outlined above are for guidance. The NRA expects to consider each site on its merits, which would include the risk to controlled water at that location, and the types and extent of pollution control measures to be implemented. The NRA may weight its judgement if technical assessments show that operation of the site would cause either increased risk or significantly reduced risk of water pollution.

3.14 The operator and the WRA should assess the vulnerability of groundwater at an individual site in terms of the physical, chemical and biological characteristics of the soil, sediment and rock beneath a landfill: these determine the extent to which a release of pollutant may damage groundwater. The assessment should include

- ► the volume and flow of groundwater
- ► the presence or absence of soil
- ► the nature of the soil (if it is relevant, which it rarely is for landfills)
- ► the presence or absence of superficial, unconsolidated deposits, and their composition
- ► the nature of the strata underlying the soil or the superficial deposits
- ► the depth of the unsaturated zone.

3.15 Each component of the soil/rock system may attenuate potential pollutants through processes such as filtration, cation exchange and biodegradation: this attenuation reduces the vulnerability of the groundwater. The British Geological Survey and the Soil Survey and Land Research Centre maintain hydrogeological/geological and soils data bases.[9]

3.16 Risk depends on a particular combination and thickness of mineral/FML liner, hydraulic conductivity and permissible leachate head. It is normally estimated from

- ► the mass flux (rate of flow x concentration) of potential pollutants through the liner, taking account of
    - ► the diluting capacity of the receiving groundwaters beneath the lining layers
    - ► the effects of any attenuating mechanisms that are demonstrably acting in the liner, and
    - ► the constraints imposed by Directive 80/68/EEC.

3.17 Controlled co-disposal takes advantage of processes which attenuate, transform or destroy specific waste components to levels comparable with those found in MSW landfills. The NRA classifies co-disposal and MSW landfills as being of the same high pollution potential.

- Sites are therefore acceptable for co-disposal **only**
    - ► if suitable engineered containment and operational safeguards are in place **and**
    - ► if site investigations have demonstrated the suitability of the location for the proposed range of waste types.

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[9] See the NRA policy document.

3.18 A risk assessment method, making use of data which are normally available from a site licence application, and aimed at assessing landfill containment needs, is under development for the Department and the NRA (GOLDER ASSOCIATES, 1995). When deciding the acceptability of co-disposal in a particular location and specifying the degree of containment necessary, the WRA should

- ▸ use the results of such a risk assessment (if they are available)
- ▸ take fully into account the views of the NRA.

Engineered and operational characteristics

The flushing bioreactor

3.19 Flushing bioreactor conditions are needed for successful co-disposal. An environment conducive both to microbial activity and the removal of solubilised materials depends on adequate moisture content and moisture flux through the wastes. This leads to a separate requirement for containment, and possibly recirculation.

- The system must control the hydraulic retention time (HRT) within the wastes to between 1 and 5 years.
- To provide this degree of control, both containment and collection systems are needed.

The characteristics of these systems are considered below.

Capping requirements

3.20 The operation of a co-disposal landfill as a flushing bioreactor, with high moisture flux to shorten the stabilization period, does **not** necessarily imply that uncontrolled ingress of rainfall should be allowed.

3.21 Instead, controlled recirculation of leachate may be carried out, both during the filling phase and afterwards below the cap, using buried irrigation pipes.

- The rate of irrigation should be adjusted so as to achieve suitable hydraulic retention times (see 5.9 and 7.11).
- Sub-cap irrigation systems should be designed to achieve even percolation of leachate through the wastes. Rapid by-pass routes must not become established: they leave volumes of poorly leached wastes which may later lead to uneven stabilisation (chapter 9).
- The irrigation systems' design should
    - ▸ allow remedial measures to maintain performance without undue disturbance to the cap and restoration layers
    - ▸ make it unnecessary to excavate into special wastes.

Special wastes should **not** therefore be deposited within the final 2m of wastes beneath the cap.

Site engineering for containment

Mineral liners

3.22 Containment may be provided by in situ or remoulded clays, bentonite-enhanced soil (BES) mixes or synthetic membranes, or by a combination of these systems. More extensive advice on site engineering is included in WMP 26B, but the most important factors relevant to co-disposal are summarised below.

3.23 In situ clays may be of variable quality, vertically and laterally. Remoulded clays, laid to a specified moisture content and compaction, may often provide a more homogeneous and reliable lining material than the in situ material.

- In order to determine whether the unmodified materials provide sufficient containment, the operator should commission a comprehensive geotechnical site survey, to be undertaken at the same time as the hydrogeological survey.
    - ► The work programme should be designed and executed by a geotechnical specialist.

3.24 Barriers of low permeability can be created by carefully mixing stable granular soil materials with bentonite, and laying the mixture to specified compaction and moisture content limits.

- ► Sodium-substituted bentonites are reputed to provide greater resistance to alteration by leachate components than calcium bentonites.
- ► Polymer treated variants are available to reduce the potential for dehydration and consequent shrinkage.

3.25 Both clay and BES liners have the advantage that their plasticity provides some self-sealing capacity if they are penetrated by material from the wastes. However, both types of liner may be subject to dehydration.

- Clay and BES liners should be covered after laying to minimise the effects of drying and cracking.

3.26 Clay and BES liners should have a hydraulic conductivity not exceeding 1 x 10^{-9} m/s, and a thickness of at least 1 metre[10]. However, for landfills destined to accept special and co-disposed wastes,

- site-specific values of maximum tolerable leakage rates may emerge from application of a risk assessment procedure and may affect liner specification
- more stringent criteria than the above may result from the proposed EU Directive on the Landfill of Wastes.

Leakage through mineral liners

3.27 Leakage may occur through any porous material, such as clay or BES. The rate for saturated systems may be estimated by application of the Darcy equation: This is shown schematically in appendix G.

3.28 The minimum rate of leakage for saturated systems takes place when the leachate drainage layer works so effectively that no liquid accumulates above the clay liner. Under these conditions the hydraulic gradient is 1.0, **irrespective of the thickness of the liner.** The annual leakage rate for a material with an hydraulic conductivity of 1 x 10^{-9}m sec^{-1} is then given by:

$$1 \times 10^{-9} \times 3600 \times 24 \times 365 = 31.5 \text{ mm year}^{-1}\text{, or } 315 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$$

3.29 However, if a head of leachate is allowed to accumulate, which is inevitable in practice, both the hydraulic head and the thickness of the liner become important in controlling the leakage rate. A leachate head of 1 metre above a 1 metre thick liner causes the hydraulic gradient to be increased to 2.0, and results in an annual leakage of 630 m^3 ha^{-1}. The leakage rate increases in a linear manner with hydraulic gradient.

3.30 In contrast, given a fixed leachate head (say 1 metre), the leakage rate decreases non-linearly with increasing depth of liner (gradients of 1/1 to 1/n+1, where n = thickness of liner in metres), so that little reduction in leakage rate is obtained with liners thicker than 3 or 4 times the permissible head.

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[10] Current UK guidance in WMP 26 (DoE, 1986) and in a Code of Practice prepared by the National Association of Waste Disposal Contractors (NAWDC, 1991)

3.31 However, the volume of attenuating material and the time required for liquids to flow through the liner, and hence the time during which attenuating mechanisms may operate before the leachate could enter an underlying aquifer, increase significantly with thickness of liner. Table 3.2 illustrates the delaying effect, assuming a leachate head of 1 metre, an hydraulic conductivity of 1×10^{-9}m sec^{-1} and an effective porosity of 0.35.

Table 3.2 Effects of liner thickness on flow-through time

Thickness (m)	1	2	5	7	10	15
Hydraulic gradient	2.0	1.5	1.2	1.14	1.10	1.07
Leakage rate (mm yr^{-1})	63.0	47.3	37.8	35.9	34.7	33.7
Flow-through time (years)	5.5	14.8	46	68	101	156

Synthetic membranes

3.32 Flexible membrane liners (FMLs) made from synthetic polymers such as HDPE have extremely low quoted permeabilities, which approach values comparable to molecular diffusion rates.

- Laying of the FMLs is a specialist operation and should be subject to third-party quality assurance protocols.

Defects in joints and panels may still occur, with between 20 and 30 defects per hectare. The American Society of Civil Engineers estimates a typical leakage rate of $0.2m^3$/ha.d (or ~7.3mm/a), assuming a leachate head of 1 metre.

3.33 FMLs are thin (typically 2.0 to 2.5mm) and may be subject to puncturing by waste components.

- To reduce this risk, a protective layer of at least 300mm of granular material above the liner is normally recommended.
- Licences should also
    - require the deposit of a first lift (~2 metres thick) of sorted, possibly composted (see 7.12), non-hazardous wastes as part of the quality control procedure, and
    - stipulate that no special waste, or other waste likely to affect the integrity of the liner, should be deposited within 4m of the top of the engineered drainage or protection layers.

Composite liners

3.34 Composite systems have been developed that combine the advantages of the very low permeability of synthetic liners with the greater mechanical resistance and self-sealing properties of clays and BES.

- ▸ In these liners, a synthetic membrane is laid in direct contact with a QA prepared mineral substrate of the appropriate permeability and thickness.
- ▸ The membrane would be protected in the way outlined above. The resulting combination can reduce leakage rates to extremely low levels.

Waste/liner interactions

3.35 Some high ionic strength liquids and organic solvents can affect the structure of clay minerals and lead to increased permeability.

- Organic solvents should not be co-disposed.

There is no evidence that the leachate quality likely to be encountered in a co-disposal site has any long term detrimental effect on non-swelling clays, HDPE or other polymers used for engineered linings.

Liner durability

3.36 Completion within a landfill operated to minimise leachate production may take several centuries. This is far beyond the horizon of confident prediction about the durability of liners, particularly synthetic membranes.

3.37 Synthetic liners have been in use for ~20 years. Material science testing procedures to simulate the effects of ageing suggest that they could reasonably be assumed to remain effective within the landfill environment for ~50 years.

- The longer term integrity of synthetic liners remains a matter for speculation and should not be relied on.

Basal drainage

3.38 The control of leachate within the waste mass is important in all landfills. It is particularly important at co-disposal sites. The operator of a co-disposal site may have to practise leachate recirculation to provide the high moisture flux needed for flushing bio-reactor conditions: the long-term performance of basal drainage systems is therefore important. Drainage blankets composed of fine grained materials may become blocked, as may drainage pipes.

- The operator should therefore specify
  - coarse drainage materials, together with
  - drainage lines designed to allow access to the pipes, so that remedial measures - such as jetting techniques - may be employed from time to time to restore performance.

There is no evidence that the design of drainage and collection systems at co-disposal sites need be any different from that at municipal waste landfills.

Chapter 4

Acceptability of wastes

Introduction

4.1 This chapter gives guidance on the intrinsic acceptability of wastes for co-disposal. This is distinct from the determination of appropriate loading rates for accepted wastes, which is discussed in chapter 5.

Precepts

4.2 This paper does not prescribe the use of particular disposal routes for particular industrial waste types; it sets the criteria for deciding the suitability of particular methods.

- The Government's policy (HMSO, 1994) is that waste management practices should be governed by the principle of the best practicable environmental option (BPEO).
- For many industrial wastes, co-disposal is likely to create the least long-term environmental impact: co-disposal will thus represent the BPEO for that waste.

4.3 Based on the research review (appendix A), the **components** of wastes, for which co-disposal is considered to represent beneficial treatment are

- acids
- heavy metals
- dilute concentrations of cyanide
- degradable organic compounds in general
- phenol and other degradable List I organic compounds
- small amounts of oil, grease and hydrocarbons.

Examples of generic waste types which may contain these components, and which have often been found acceptable for co-disposal, are shown in table 4.1.

4.4 The appropriateness of co-disposal for a particular waste may need to be assessed case by case. The assessment

- would be based on the technical criteria given in this chapter, and
- might involve the analysis and testing of the waste.

4.5 The WRA may assign some wastes to a positive list. This assignment would indicate the waste's acceptability for co-disposal, either generally or at particular sites. It would be based on experience of

- the suitability of the waste
- the consistency of the waste's characteristics.

The operator would then need to test these wastes only for on-site verification, and compliance (to control loading rates).

Criteria for wastes NOT suitable for co-disposal

4.6 The criteria to be used to identify wastes that are **not** suitable for co-disposal are summarised in table 4.2. They are discussed from paragraph 4.8 on.

Qualitative criteria

4.7 Criteria for acceptability are based on:

(i) excluding wastes which are better disposed of by other methods such as incineration;

(ii) ensuring that the waste is capable of interacting with the decomposing municipal waste;

(iii) verifying that leaching of solid wastes and sludges during the lifetime of the site will leave a non-hazardous, non-polluting residue.

Some of the criteria may appear similar to some of those described in Annex III of the EC Directive on Hazardous Waste (91/689/EEC); but there is a fundamental difference of purpose.

- The criteria in 91/689/EEC are used to decide whether or not the waste is hazardous.

- The criteria given below are used solely to decide whether or not a waste (which may or may not be hazardous or special) is acceptable for co-disposal.

Waste incapable of interaction

4.8 No waste should be accepted for co-disposal, or deposited in co-disposal areas, in a physical form in which it is unable to interact with the biomass, either directly or by leaching. Such wastes should either be treated, incinerated or landfilled in separate mono-disposal areas. Asbestos waste, tarry wastes and other hydrophobic wastes would be included in this category.

Quantitative criteria

Flammable and low-flashpoint

4.9 No waste that is in liquid or sludge form, and **either** is flammable (capable of burning unsupported at 40°C or less) **or** has a flashpoint of less than 55°C should be co-disposed or landfilled.

Organic liquid

4.10 No organic liquid waste, or aqueous waste containing >1% immiscible organic liquid should be co-disposed.

4.11 The acceptability of aqueous wastes with significant[11] organic content must be judged by

- the characteristics of the organic components **and**
- the fate of those components within the fill.

To do this, tests similar to the anaerobic bioassay test (ABT) - outlined in paragraph 4.15 below - may be needed.

Explosive or strongly oxidising or violently reactive

4.12 No waste which

- is explosive **or**
- is strongly oxidising **or**
- will react violently with water or organic matter

should be co-disposed or landfilled.

Containing heavy metal

4.13 If a liquid waste contains >100mg/l heavy metal in solution, it should be subject to a precipitation test[12]. This will show whether attenuation processes will be impeded by organic ligands in the waste.

- If the soluble heavy metal content then exceeds 20mg/l, the waste should not normally be co-disposed.

- The waste may, however, be co-disposed if further evidence shows that the metals will be attenuated, or the ligand will be rapidly degraded, or both.

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[11] As used here, "significant" means >5% total organic content as measured by TOC.

[12] The test should consist of pH adjustment to 10.5, mixing for 5 minutes, followed by settlement for 30 minutes.

Special (toxic or polluting)

4.14 Some solid wastes and sludges have toxic or polluting components. These wastes and sludges should **not** be co-disposed if, after active leachate and gas management ceased, they could still release unacceptable concentrations of any component.

- Acceptable concentrations will be site-specific. They should be decided in consultation with the NRA (in Scotland, the RPA).
- If, unusually, the NRA (RPA) has not provided a specific opinion, or if there is no site-specific assessment of the risk to receiving waters, target concentrations should be set at levels substantially more stringent than drinking water standards.

The long-term behaviour of the waste should be assessed by a leaching test on the lines foreshadowed in appendix B.

List I organic

4.15 If a waste may contain any organic substance on List I of the Groundwater Directive[13], it should be subject to an anaerobic bioassay test (ABT[14]). This will indicate

- whether the List I organics will be degraded within the landfill
- whether they are likely to inhibit normal landfill degradation processes.

4.16 For solid wastes and sludges, the test should be applied to an eluate produced by leaching the waste with distilled water for 24 hours at a liquid to solid ratio of 4:1.

- If published data on the anaerobic fate and impact of the List I organic compounds are extensive enough, they may be used as an alternative to carrying out the ABT.

4.17 **No** waste containing a significant quantity and concentration of any List I substance should be landfilled **unless** a site investigation has shown, to the satisfaction of the NRA (in Scotland, the RPA) and the WRA, that the location is suitable.

Cyanide

4.18 **No** liquid waste containing > 100mg/l total cyanide should be landfilled. **No** solid waste containing > 100mg/kg total cyanide should be co-disposed.

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[13] 80/68/EEC, which prohibits direct discharges containing List I substances.

[14] The ABT protocol is given in appendix C.

Other wastes

4.19 Wastes containing the following substances will not generally be acceptable for landfilling:

- PCBs, PCTs[15]
- PBBs, PCNs[16]
- PAH
- organometallic compounds
- non-degradable pesticides.

Disposal of drummed waste

4.20 As a general principle drummed wastes should **not** be deposited in landfills.

4.21 Solid wastes and sludges in drums should only be accepted for co-disposal in limited quantities, **and** only if the operator can show that efficient leaching will will occur, given the method of deposit and the nature of the waste.

4.22 Liquid wastes should be decanted from drums prior to co-disposal. The empty drums should either be disposed of separately after crushing or be removed from site for disposal elsewhere.

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[15] defined as any material containing more than 50 ppm (mg/kg) PCB or PCT.

[16] The environmental properties of these compounds are similar to those of PCB. The defining limit, 50 ppm (mg/kg), is therefore extended to PBB and PCN for the purposes of this paper.

4.23 If the WRA decides that disposal of drummed wastes is acceptable, it should be carried out in accordance with the NAWDC Code of Practice (NAWDC, 1989).

Table 4.1 Examples of waste types that may be suitable for co-disposal

Bottom ash from waste incineration
Fly ash from waste incineration
Air pollution control residues from incinerators
Products from waste solidification processes
Contaminated soils
Industrial effluent treatment sludges and filter cakes
Biological treatment sludges and filter cakes, including sewage sludge
Animal and food industry wastes
Tannery and fell-mongering wastes
Brewery wastes
Adhesive wastes
Detergents, fats and greases in water
Paint spray booth effluents
Interceptor wastes and tank sludges
Alkaline degreasants
Cutting oils/cooling oils
Metal finishing wastes
Aqueous effluents containing **degradable** organics from chemical manufacture
Acids, alkalis.

Table 4.2 Wastes that should NOT be co-disposed

Organic liquids	
Aqueous waste with:	>100 mg/l strongly complexed heavy metals, or
	>100 mg/l total cyanide as CN, or
	>1% non-miscible organic content, or
	significant organic content (>5% total organic content, as measured by TOC) **unless** technically justified by an individual evaluation of the suitability for landfilling of the specific organics
Solid waste which:	is hydrophobic, or
	is in a massive, non-leachable form, or
	fails long-term leaching criteria
	contains >100mg/kg total cyanide, as CN
	contains asbestos
Any waste containing:	PCBs, PCTs[17]
	PBBs, PCNs[18]
	PAH
	organometallic compounds
	non-degradable List I organic compounds
Any waste which is:	explosive
	oxidising
	reactive
	flammable
	has a flashpoint of less than 55°C.

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[17] See footnote 15.

[18] See footnote 16.

Chapter 5

Loading rates

5.1 This chapter discusses the factors which should be used to regulate inputs of co-disposed wastes. It indicates how to decide the maximum acceptable loading rates for wastes containing particular components.

General considerations

5.2 Loading rates may be controlled

- to control inputs of polluting or hazardous components
- to reflect physical stability limitations
- to anticipate effects on site hydraulics
- to deal with water balance
- for aesthetics.

Any one of these may become the overriding control on the input of a particular waste.

Dewatered sludges and operational problems

5.3 Some wastes, particularly some partly dewatered sludges, may create operational problems if they make up too high a proportion of the waste inputs.

- The physical stability and load-bearing capacity of the tipping area may be badly affected.

- If the sludge is not adequately covered by other dry wastes, it may be carried by vehicle wheels on to site roads and external roads.

5.4 An example is dewatered sewage sludge. Field trials conducted by the Water Research Centre (BLAKEY, 1991) found that a practical upper limit for this material is approximately 10% of total solid waste inputs, even though no effects were observed on heavy metal concentrations in the leachate at this loading.

Low permeability materials

5.5 Solid wastes must be deposited in a way that allows efficient leaching to occur. Upper limits may therefore have to be placed on loadings for wastes with a tendency to form low permeability layers.

- ▸ This tendency occurs in (for example) filter cakes arising from the use of lime in liquid waste treatment, and in incinerator residues, at loadings as low as 5%.

Any loading limit imposed for this reason must take into account the beneficial effects of operational methods that are designed to mix the industrial waste with the municipal waste, avoiding the formation of discrete layers.

Other solid wastes

5.6 The objectives of co-disposal are unlikely to be met if the solid co-deposited wastes constitute more than 20% of the total inputs of municipal and other biodegradable solid waste. Site-specific factors will often limit inputs to less than 20%.

Liquid wastes

5.7 At sites receiving liquid wastes (whether special or non-special), inputs may be limited by the capacity to treat and discharge leachate, particularly if limits on leachate levels are included in the waste management licence.

- The WRA should normally use leachate level limits as the primary means of licence control over liquid waste inputs.

- Water balance calculations are **not** usually sufficiently reliable to be used for this purpose. They may be useful for operators, who could consider making liquid waste input rates conditional upon the volumes of leachate discharged during a specified period, such as 6 months.

Types of waste input control

5.8 As a result of the foregoing considerations, several types of input control may be appropriate for co-disposal. They include the total quantity or rate, or both, of

- ▸ special solid waste
- ▸ liquid waste
- ▸ particular sources or types of special wastes
- ▸ input of specified components in special wastes.

5.9 Licence conditions should include a combination of some or all of these types of control.

5.10 The aspect which normally requires the greatest degree of detailed technical consideration is the setting of limits on individual polluting or hazardous components. This requires first of all an assessment of the capabilities of the individual landfill as a reactor.

Capability of the landfill as a reactor

Reaction zone

5.11 The reaction zone is that portion of the methanogenic waste with which liquid waste or leachate from solid co-disposed waste will come into contact, either directly or as a result of leachate recirculation, before reaching a point where leachate is removed from the site for treatment or disposal.

5.12 The hydraulics of the landfill, and the effects of recirculation on the reaction zone volume, must be carefully considered: they will determine the quantity of special wastes which may be co-disposed.

5.13 The operator should assess the hydraulics of the reaction zone, paying particular attention to the possibilities of short-circuiting and dead volumes. Factors to be considered include

- dimensions of zone and depth of leachate
- location and method of liquid application or leachate recirculation, or both
- location and method of leachate abstraction for treatment or disposal
- any other leachate losses from the site
- existence of any known or suspected barriers to flow within the reaction zone
- existence of any rapid flowpaths within the reaction zone.

Hydraulic retention time

5.14 The reaction zone must provide an average hydraulic retention time (HRT) of at least 1 year for applied liquid wastes and for leachate from special solid wastes. A schematic example of HRT calculation is shown in appendix G.

5.15 Hydraulic retention time should be taken as the retention time before leachate reaches a point where it will be removed from the site for treatment or disposal. Its estimation should be based on all known or estimated liquid inputs (e.g. liquid wastes, effective rainfall) and the known or estimated total moisture content of the wastes within the reaction zone.

5.16 A longer HRT may be advisable if in the WRA's view there is a significant risk of short-circuiting. Where appropriate, leachate recirculation may be employed to utilize a larger effective reaction zone and this may lead to a longer average hydraulic retention time.

5.17 The landfill design may incorporate high permeability basal leachate drainage layers. They route leachate rapidly to abstraction points. In this design, the time taken for vertical percolation from the lowest layer containing co-disposed waste will

- be affected by the moisture content of the intervening waste layers
- will itself set the limiting hydraulic retention time.

A depth of at least 4m of municipal or similar waste should be provided between any co-disposed wastes and the basal leachate drainage layer.

Methanogenic activity

5.18 Degradation and attenuation of components is based on the premise that components will come into intimate contact with decomposing solid waste which is actively methanogenic.

5.19 The WRA should therefore base loading limits on

- the quantity of methanogenic waste which will come into contact with components of the co-disposed wastes (i.e. the reaction zone), and

- the level of biological activity.

To do this, separate approaches are needed for solids and liquids.

Solids

5.20 The general approach to control for **solid** wastes and sludges is to relate leachable[19] components to current or recent inputs of municipal or similar wastes.

- This only works if methanogenic conditions are going to become established fairly rapidly. The WRA should judged this from

    - monitoring results in previously filled areas of the site (if they are available), and

    - the proportion of readily-degradable solid wastes entering the site.

A leaching test for assessing leachable components of solid wastes is under development: see appendix B.

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[19] rather than total

5.21 When calculating acceptable loadings, a distinction should be made between

- bioreactive wastes which *contribute* to the co-disposal capabilities of the site (e.g. municipal and certain non-hazardous food, agricultural and organic wastes)
- bioreactive wastes which *dilute* the capability of the site (e.g. construction and demolition wastes and many non-hazardous industrial wastes)
- bioreactive wastes which constitute *a load* on the co-disposal capability (e.g. most special wastes).

5.22 It may sometimes be difficult to make precise distinctions between what is bioreactive and what is not. Unless site-specific information indicates otherwise,

- non-hazardous industrial wastes should be regarded as diluting
- municipal (including commercial) waste should be regarded as bioreactive.

5.23 For solid waste co-disposal, the proportion of bioreactive wastes should be greater than 50% of the total inputs, to ensure that an adequate level of activity will develop.

- For the implementation of this precept, see the second section of the example in figure 6.1 on page 54.

THE ROLE OF GRANULAR INERT MATERIALS

5.24 The presence of granular inert materials within biodegradable wastes may be beneficial in promoting methanogenesis, providing physical stability and assisting the even flow of leachate.

5.25 However, some sites may need segregation of inert or diluting wastes into separate disposal areas

- to ensure a high enough biodegradable content in the co-disposal areas, and
- to prevent low-permeability materials from interfering with the even passage of leachate through the wastes.

Liquids

5.26 The general approach for **liquid** wastes is to limit total components of the liquid waste by reference to

- the volume of methanogenic waste already in the landfill (the reaction zone), and
- the landfill's actual level of biological activity.

5.27 Site monitoring data should be used to assess the actual level of methanogenic activity. Liquids should not be co-disposed unless the results show clearly that stable methanogenic conditions are established and that a sufficiently high level of activity continues.

5.28 Average methanogenic activity may be assumed if the following conditions obtain:

average reaction zone temperature	$\geq 25°C$
average leachate pH value	6.8 - 8.5
average leachate BOD/COD ratio	≤ 0.3
gas production rate	$> 5m^3/m^3$.a .

These are indicative values only, and other data may assist in assessing the level of activity.

Specific component loading limits

5.29 Suggested loading limits are given in table 5.1 for landfills with an average level of methanogenic activity.

5.30 Where the WRA has reason to believe that the rate of activity may be significantly higher or lower than average, it may consider increasing or decreasing loading limits for organic components, **with the exception of** the limits for oil, grease and hydrocarbons.

5.31 More information on the technical background to the limits in table 5.1 may be found in appendix A, and in paragraphs 5.32 to 5.42 below.

5.32 **Acids** The loading limit in table 5.1 has been set at the lower end of the range observed in experimental studies. The limit of 100eq/t may be visualised in more practical terms by considering a waste acid which is 1M in H^+ (e.g. a 3.5% hydrochloric acid waste). A loading of 100eq/t equates to $1m^3$ of waste acid per 10 tonnes of refuse.

5.33 **Heavy metals** Limits are given in table 5.1 for seven common metals: they are set at the lower end of the range observed in experimental studies. Others will be added as more data become available.

5.34 For other toxic metals, including antimony, selenium and tellurium, it is suggested that a cautious approach be taken and a limit of 10g/t be applied to each metal, the same as for cadmium, unless data are obtained to show that a higher limit is appropriate.

5.35 **Cyanide** The assessment must include both free and complexed cyanide. The limit in table 5.1 is at the lower end of the range observed in experimental studies.

5.36 **Oil, grease, hydrocarbons** The assessment should be based on non-volatile components extractable with light petroleum. The limit is given as a one-off rate per tonne of refuse because there is no definite evidence that these components are degraded in landfills: they are removed by sorption onto other waste components.

5.37 **Phenols and List I organics** Limits are given for phenol, which has been widely studied both in methanogenic refuse and in more conventional digesters. The loading limit in table 5.1 is at the lower end of the range observed in experimental studies in methanogenic refuse.

5.38 Other phenols and List I organics should be evaluated by reference to the degradability of phenol, and controlled using the same limit.

5.39 Some List I organic compounds can be degraded in landfills while others are unsuitable. Limits should be applied to wastes for which the waste producer answers yes to any of the following questions:

- Does the process from which the waste arises produce any List I organic substance either as the main product or as a by-product?
- Are any List I organic substances used in the process from which the waste arises?
- Are any List I organic substances used in cleaning or lubrication?

5.40 For any compound so identified, the operator must propose a value for the expected degradation rate in landfill (the landfill loading potential): the value may be based on the results of an approved anaerobic bioassay test (ABT) or upon published data (if they are available).

5.41 The degradability of the compound under methanogenic conditions should be compared with that of phenol under similar conditions, and the concentration in the waste expressed as phenol equivalents. The loading limit in table 5.1 for phenol should then be used to control the sum of all inputs of phenol plus any List I organics.

5.42 **Organic compounds (general)** Many aqueous liquid wastes and sludges from pre-treatment contain a mixture of simple degradable organic compounds, such as carboxylic acids, alcohols, aldehydes and ketones. Inputs of total organic carbon (TOC) should be limited to rates which are modest compared to typical rates of organic carbon metabolism in decomposing municipal waste.

Application of loading limits to solids and liquids

5.43 For **liquid** wastes, site-specific loading limits should be based on the size of the reaction zone and the limits in table 5.1.

5.44 For **solid** wastes, site-specific loading limits should be based on

- the limits in table 5.1 **and**
- the inputs of bioreactive wastes entering the site during the previous month.

Capacity which remains unused at the end of any one month should not be carried forward.

5.45 The purpose of this limitation is

- to encourage the uniform distribution of the co-disposed wastes throughout the waste mass
- to avoid the risks of building up localised 'hot-spots' where the treatment capacity of the landfill could be exceeded by large volumes of co-disposed waste.

The practical implementation of this concept is considered in chapter 6.

5.46 For degradable organics, the loading limits are given as a *rate per unit volume of reaction zone* for liquid wastes, and as a *one-off loading per tonne of biodegradable wastes* for solid wastes.

- The rate per unit volume is appropriate for liquid wastes, because it uses the landfill as a reactor on a sustainable basis for as long as biological processes remain sufficiently active.
- For solid wastes the only opportunity for co-disposal is during infilling, so the loading limit reflects the anticipated capacity over a period of time following infilling.

5.47 The organic loading limits for solid wastes are derived in part from those for liquid wastes, applied for a period of time; and in part from the results of lysimeter studies with solid wastes.

5.48 Biological activity would normally be expected to continue for more than 10 years at a significant rate. The limits recommended in table 5.1 for solid wastes correspond to much shorter periods, typically from 1 to 5 years. This represents a margin of safety, and is considered necessary for four reasons.

1 The duration and intensity of biological activity may vary from site to site and cannot be guaranteed for as long as 10 years.

2 Solids co-disposal is based on the *expectation* that methanogenic conditions will become established and this may take longer at some sites than at others.

3 There is some risk that high concentrations of compounds such as phenol or cyanides, arising from a one-off loading, could inhibit biological processes; repeated inputs of smaller quantities in liquid wastes would not, because they would be continuously degraded, and could be curtailed if any evidence of inhibition was discovered.

4 The interaction of solid waste components with municipal waste depends upon leaching: some allowance has to be made for any delay or inefficiency in leaching and subsequent mixing with municipal wastes.

Table 5.1 Component loading limits for co-disposal

	Solid wastes (leachable components)		**Liquid wastes** (total components)	
Waste component	limit	units	limit	units
acids	0.1	10^3eq/t	0.1	10^3eq/t
heavy metals				
Zn	100	g/t	100	g/t
Cu	100	g/t	100	g/t
Ni	100	g/t	100	g/t
Cr	100	g/t	100	g/t
Pb	100	g/t	100	g/t
Cd	10	g/t	10	g/t
Hg	2	g/t	2	g/t
As	100	g/t	100	g/t
others	10	g/t	10	g/t
cyanide (all forms), as CN	100	g/t	1	g/m^3.d
phenol, as C_6H_6OH	2	kg/t	5	g/m^3.d
oil, grease & hydrocarbons	2.5	kg/t	2.5	kg/t
TOC, as C	5	kg/t	10	g/m^3.d
List I organics, as phenol	ABT		ABT	

Additional components to be considered

5.49 Ammoniacal nitrogen and chloride inputs should also be assessed, on the basis that all of the applied loading will appear in the leachate.

- High NH_3-N concentrations can inhibit landfill degradation processes, and may represent an additional load on leachate treatment plants.
    - Although the chloride ion is not itself inhibitory to anaerobic processes, the cations most often associated with it (Na, K, Ca, Mg) can reach inhibitory levels in some industrial wastes.

5.50 Applied loadings must not cause any impact on normal landfill processes or lead to the capacity of leachate treatment and disposal systems being exceeded.

5.51 No loading limits are proposed in table 5.1 for ammoniacal nitrogen, chloride, or major cations. The WRA should take account of their effect on leachate concentrations, and of the following published information (Mosey, 1974) on inhibition of anaerobic digestion:

NH_3-N	optimum	50 - 1,000 mg/l
	moderate inhibition	1,500 mg/l
	strong inhibition	3,000 mg/l
Na^+	optimum	100 - 200 mg/l
	moderate inhibition	3,500 - 5,500 [Cl^- 5,300 - 8,500] mg/l
	strong inhibition	8,000 [Cl^- 12,170] mg/l
K^+	optimum	200 - 400 mg/l
	moderate inhibition	2,400 - 4,500 [Cl^- 2,000 - 4,000] mg/l
	strong inhibition	12,000 [Cl^- 10,650] mg/l

These numbers were derived from studies on conventional anaerobic digesters and are given for information only. Due consideration should be given to

- the possible acclimatization which can occur in landfills
- the beneficial effects which the solid wastes can sometimes have in reducing inhibitory concentrations by ion-exchange and adsorption processes.

5.52 The WRA and the operator should exercise caution before accepting liquid or solid wastes containing high concentrations of sulphate. These can in some circumstances lead to the generation of large concentrations of sulphide in solution.

- Odour problems have occurred at some sites because of emissions of hydrogen sulphide gas.
- Some sites have experienced difficulty in meeting discharge limits for disposal of leachate to sewer.

This paper does not recommend a loading limit.

5.53 At some landfills, plasterboard and gypsum in locally high concentrations have caused severe problems of sulphide generation. At others, prolonged deposit of liquid wastes containing ~5% sulphate as SO_4 has resulted in no observable sulphide problems. The WRA should bear in mind that sulphur is an important component of landfills because of the role of sulphide in the precipitation of metals.

Chapter 6

Acceptance arrangements

6.1 This chapter discusses acceptance arrangements, including

- prior assessment of wastes
- checks on arrival at the site
- record-keeping of wastes received.

Prior assessment and approval

6.2 The special waste Regulations impose prenotification requirements. Some site licences oblige the operator to have the WRA's approval for the input of special waste. Sound co-disposal nevertheless demands further safeguards.

Technical assessment

6.3 Waste destined for co-disposal must be assessed

- in advance
- by a technically competent person

before a decision is made about its acceptability for co-disposal at a particular site.

Characterisation

6.4 The waste will often have to be sampled, analysed and tested to characterize it and decide the loading limits. This is referred to as Level 1 testing: see the proposed European standard scheme shown in table 6.1.

Data in the Notes and the Technical Control Document

6.5 The special-waste consignment note, like the Duty of Care transfer note[20], must adequately describe the waste so that it can be soundly managed.

6.6 If the method of management is co-disposal, the following information[21] should be provided

- waste producer
- proposed disposal facility
- process source
- general description of the waste, including physical properties
- quantity and frequency of arising
- results of chemical analysis, ABT and leaching tests undertaken on the waste, including the concentrations of any components subject to loading rate controls
- sampling frequency for regular arisings
- sampling methodology
- any special precautions to be observed during collection or disposal.

6.7 Most major operators have their own systems of technical control documents (TCDs). For practical reasons (see paragraph 6.5, 6.10 below), they may wish to align the TCD with the statutory note.

Waste testing hierarchy

6.8 Testing and analysis of wastes should be organized at three levels (summarised in table 6.1).

- ▸ The first level (Level 1) is *comprehensive characterization testing.* This is needed as part of the prior assessment, to determine the intrinsic acceptability of the waste for co-disposal and any loading limits.

- ▸ Level 2 is *compliance testing*, in which the waste is re-tested at the specified frequency to look for any changes in the basic characteristics of the waste or in the concentrations of restricted components. The scope of Level 2 testing may be less comprehensive than for Level 1. European standards suitable for Level 2 testing, including sampling methodologies, are currently being developed by CEN (European Committee for Standardization).

- ▸ Level 3 is *on-site verification*, usually consisting of quick, simple tests and checks to ensure that the waste, when it arrives at site, matches the description in the consignment note or transfer note and the Technical Control Document.

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[20] used for other waste

[21] much of which will be included on any well-prepared consignment note or transfer note

Table 6.1 Waste Testing Hierarchy

Level 1:	COMPREHENSIVE CHARACTERIZATION *Use for prior assessment to determine intrinsic acceptability and loading limits.*
Level 2:	COMPLIANCE TESTING *Assess changes in characteristics and component concentrations.* *Use for monitoring adherence to loading rate limits.*
Level 3:	ON-SITE VERIFICATION *Confirm identity and description of waste.* *Check for health and safety risks during handling on site.*

Input control at the landfill

6.9 Three aspects of input control should be provided for:

1. documentation check
2. on-site verification testing (Level 3)
3. retention of samples for retrospective (Level 2) testing.

These are now discussed.

Documentation

6.10 Documentation procedures are similar at most sites. Typically the site holds a copy of the Technical Control Document for any waste which has been notified or approved for disposal.

- On arrival at the site, the vehicle driver presents his copy of the Document, signed by the waste producer's representative, to confirm the date and time of waste collection.

- The gatehouse staff compare the two documents.

- The vehicle is **not** allowed to proceed to the reception or disposal area unless the comparison is satisfactory.

6.11 If the TCD is the unique control document at this stage, the operator must run an adequately audited sytem for tying the TCD to the statutory note. This may be easier if the documents are alike in core content and design.

On-site verification testing

6.12 Procedures for on-site verification (Level 3) testing may vary from simple visual examination to a range of physical and chemical tests. The basis of the procedures, by waste category, should be specified in the site licence or working plan.

6.13 For liquid wastes it is common to inspect and test every load. Solid wastes and sludges are, on the whole, less frequently tested.

6.14 A test should only be done if it serves to ensure

- that the waste broadly matches the description on the documents
- that the waste will not cause any immediate health and safety problems during disposal (e.g. evolution of heat or gas).

6.15 On-site tests for liquid wastes nearly always include

- pH
- flammability
- odour
- visual check for non-aqueous liquid.

6.16 On-site tests sometimes include additional checks such as

- gas evolution at high and low pH
- cyanide analysis.

6.17 The results of on-site testing should be recorded on the TCD. TCDs should be retained within the system.

Retrospective testing

6.18 Representative samples should be taken from every load of special waste and retained for a specified period. Their purpose is primarily for Level 2 (compliance) testing on a proportion of the samples selected at random; but also in case of a query about any individual waste.

Frequency of tests

6.19 The frequency of Level 2 testing should be specified on the Technical Control Document. The WRA should adopt a reasonable approach: frequency must be related to

- the process source
- the expected variability of the waste
- the consequences of significant changes in its composition.

6.20 A possible scheme for specifying the frequency of testing is to assign a ranking number to each waste, e.g. from 1 to 50.

- A ranking of 1 would require every load (i.e. 1 in 1) to be tested. This might be applied, for instance, to a waste arising from a new chemical production process.
- As more information accumulates about a particular waste, its ranking number could be increased. A ranking of 10 would require 1 in every 10 loads to be tested.
- With a range of from 1 to 50, the minimum requirement would be for 2% of loads to be tested.

Retention of samples

6.21 In current practice, samples are retained for periods from two weeks to one month; the proportion of samples analysed varies from ~1% to 25%.

6.22 At one major solids co-disposal site, which receives mainly filter cake and treatment plant sludge, a randomly chosen sixth of the samples is analysed: the WRA finds this generally satisfactory.

- The proportion should be variable, and should depend on the ranking assigned to individual wastes.

6.23 Most Level 2 testing is retrospective: its primary role has been to monitor adherence to loading rate limits. Advance testing may reasonably be required if a low ranking number is assigned. It will probably be necessary only in exceptional circumstances.

Monitoring adherence to loading limits

Solid wastes

6.24 For solid wastes arising on a regular basis, the results of Level 2 compliance testing should be the main source of information used to monitor and control loadings of restricted components into the site. These results will be used in combination with any data already available from Level 1 testing.

Liquid wastes

6.25 For liquid wastes, it may be more appropriate to analyse a weekly or monthly composite, prepared by mixing sub-samples taken from every load. This can provide more accurate estimates of component loadings than a random proportion of sub-samples, and at lower analytical cost.

6.26 If this approach is used, samples of individual wastes should still be taken, and retained for a period defined in the licence, in case of queries about particular wastes.

Waste input accounting procedure

6.27 So that the WRA can monitor adherence to loading limits in the waste management licence, the operator should account monthly for

- ▸ biodegradable wastes
- ▸ inert or diluting wastes
- ▸ special wastes
- ▸ restricted components.

6.28 The accounting procedure should incorporate checks on any non-component loading limits, such as the total quantity of liquid or the proportion of special to biodegradable waste.

- ▸ This type of accounting is readily accomplished on PC-based spreadsheets: an example used by Warwickshire WRA has been described in detail by QUINN AND HEAVEN (1992).

6.29 An example of an appropriate format for monthly reporting for solid wastes is shown in figure 6.1. By linking the loading limits for solid special wastes to biodegradable inputs in the **previous** month, the same format can be used by operators for day to day control of inputs during the month.

6.30 Arrangements for up-dating estimates of restricted component inputs, based on Level 2 testing, should be site-specific and to some extent waste-specific. The approach used at a particular site should be declared in the Working Plan.

- Licence conditions should ensure that these procedures can only be varied with the permission of the WRA.

6.31 Monthly inputs of restricted components should be calculated from the sum of inputs from all the individual special wastes containing that component.

Recording/reporting of waste inputs

Waste locations

6.32 The operator must log and record, in three dimensions, the locations within the landfill of all deposits of special waste.[22] The information will be needed

- ▸ for leachate management
- ▸ to confirm the leaching of wastes
- ▸ to assist any investigations needed for site completion.

6.33 The operator should record

- ▸ the locations being used for co-disposal in any particular month
- ▸ the wastes that were deposited during that month.

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[22] This is a requirement of the Special Waste Regulations.

Input statistics

6.34 The long-term record of the inputs of wastes by category, and of quantities of restricted components, is the source of regional and national statistics. They are essential for efficient planning of waste management. Forthcoming European legislation will probably require national reporting of wastes data.

- ► Licence conditions should require records to be kept, and reported to the WRA on a regular basis, e.g. monthly or quarterly, in an appropriate format.

Classification and coding

6.35 All operators and all WRAs should use a standardised waste classification and coding scheme for recording waste inputs. To be useful, the format must be suitable for database management. The classification scheme for co-disposed wastes should include information on three separate aspects,

1. origin (e.g. industrial sector)
2. material properties and process source
3. major chemical constituents.

6.36 No standard European or UK system provides all three facets.

6.37 A European Waste Catalogue (EWC) has been issued[23]. It is a hybrid list. It combines some aspects of industrial classification, and some of material properties and process; but it does not in its present form separate the two in a way convenient for record-keeping.

6.38 A hazardous waste list is being prepared[24], but is unlikely to provide a suitable basis for record keeping. A contract to prepare a draft coding system is currently being sponsored by the Department.

6.39 In the meantime, a satisfactory basis for recording inputs of major chemical constituents, including restricted components, already exists in the UK.

- Components should be classified using the coding system given in WMP 26 (1986). It is reproduced here at appendix E.

- Concentrations should be recorded by the codes given in WMP 2 (1976), also reproduced here at appendix E.

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[23] in pursuance of article 1(a) of the Framework Directive on Waste (75/442/EEC), as amended by 91/156/EEC

[24] in pursuance of article 1(4) of the Hazardous Waste Directive (91/689/EEC)

Figure 6.1 Example of monthly accounting format for solid waste co-disposal

MONTH: MAY/94	**UNITS**	**ACTUAL**	**LIMIT**	**PASS/FAIL**
BIODEGRADABLE WASTES IN PREVIOUS MONTH	tonnes	*20000*	▨	▨
INERT/DILUTING WASTES IN PREVIOUS MONTH	tonnes	*10000*	▨	▨
GENERAL RESTRICTIONS				
TOTAL SPECIAL WASTE	tonnes	*2400*	▨	▨
TOTAL LIQUID WASTE	tonnes	*400*	▨	▨
TOTAL SLUDGE WASTE	tonnes	*1000*	▨	▨
RATIO BIODEGRADABLE/TOTAL [20,000/30,000]	%	67	**50**	pass
RATIO SPECIAL/BIODEGRADABLE [2,400/20,000]	%	12	**20**	pass
RATIO (LIQUID + SLUDGE)/TOTAL [1,400/30,000]	%	4.6	**10**	pass
COMPONENT RESTRICTIONS				
ACIDS	keq	200	2000	pass
HEAVY METALS	kg			
Zn		1850	2000	pass
Cu		500	2000	pass
Ni		900	2000	pass
Cr		400	2000	pass
Pb		800	2000	pass
Cd		100	200	pass
Hg		10	40	pass
As		100	2000	pass
Others		80	200	pass
CYANIDE	kg	50	2000	pass
OIL, GREASE, HYDROCARBONS	tonnes	15	50	pass
TOC	tonnes	30	100	pass
LIST 1 ORGANICS (AS PHENOL EQUIVALENTS)	tonnes		▨	▨
a		4.2	▨	▨
b		1.7	▨	▨
c		1.5	▨	▨
etc.			▨	▨
phenol		12.5	▨	▨
phenol equivalents		19.9	40	pass
CHLORIDE	tonnes	20	▨	▨
NH_3-N	tonnes	5	▨	▨

Licence conditions in bold; *input data in italics;* calculated values in ordinary type

Notes to the table:

1. Component limits calculated from actual waste inputs and loading limits in table 5.1.
2. Component inputs calculated from sum of components in all individual waste streams (hypothetical data shown).

Editorial note in the consultation version: The format of this table will be reviewed before final publication for possible incompatibilities with other recording and statistical systems.

Chapter 7

Disposal methods

7.1 This chapter considers aspects of site operation particularly relevant to co-disposal, including

- the location of co-disposal areas within sites
- the methods of waste deposit
- staffing and control of operations
- ensuring that the optimum biological and hydraulic conditions are provided
- the effect of waste pre-treatment.

Location of disposal areas

HRT

7.2 Disposal areas for special wastes must be located so as to provide a hydraulic retention time (HRT) of at least 1 year for liquid wastes (or for leachate from solid wastes). See the glossary and appendix G for calculation of HRT.

7.3 HRT is affected by the depth of saturation maintained in the wastes. A greater saturated depth will lead to a higher total moisture content, and hence a longer HRT. The WRA must balance the benefits of this for co-disposal processes against the need to minimise risks to groundwater. At many landfills only a shallow saturated depth will be acceptable on the base of the site and this may limit the opportunity for co-disposal.

Minimum separation distances

7.4 The licence should stipulate minimum separation distances between any deposit of special waste (or waste likely to affect the integrity of the liner) and the base, sides and top of the landfill. Their purpose is

- to reduce the risk that short-circuiting will have a detrimental effect on HRT or on leachate management

- to prevent direct contact between special wastes and any lining or capping materials

- to reduce the risk that plant roots or excavations during the aftercare period could accidentally penetrate special wastes.

7.5 Separation distances should be site-specific; but the minimum values likely to be safe are

- at least 4m biodegradable waste beneath co-disposed special waste
- at least 10m lateral distance from site edge
- no special waste within 2m of restoration or capping layers.

Tipping areas

7.6 At most co-disposal sites, special solid wastes are deposited at a joint tipping face used for municipal, commercial and non-hazardous industrial wastes.

7.7 At some sites, particularly those receiving large tonnages, there are separate tipping areas for municipal wastes and other wastes. The special wastes may then be deposited with the non-hazardous industrial and commercial wastes.

- ▸ There is no objection in principal to this practice; **but**
- ▸ the WRA must carefully consider the biodegradable content of the non-hazardous industrial and commercial wastes, particularly if construction and demolition wastes are also being deposited (see paragraphs 5.4, 5.12).
  - The risk is that the proportion of biodegradable material could be too low to support co-disposal.

7.8 In general, special solid wastes should be deposited at the same tipping face as the most biodegradable wastes i.e. municipal wastes.

Inert wastes

7.9 The operator should consider running a separate tipping area for inert or diluting wastes, if they are likely to interfere with the free flow of leachate or the level of biological activity.

7.10 At a landfill where liquid wastes are to be deposited, the operator should consider **not** depositing special solid wastes in areas that will later be excavated for liquid disposal trenches or injection zones. The decision will depend on the relative quantities of liquid waste and special solid waste.

Disposal operations

Cellular tipping

7.11 Cellular tipping methods have become established at the majority of landfills. Their impact upon co-disposal must be considered carefully.

7.12 If the cells' construction constrains the movement of leachate between cells, each cell may have to be considered separately when planning leachate management and calculating HRT. This may curtail the opportunities for co-disposal.

- ► If the hydraulic barriers between cells are significantly lower than the allowed depth of leachate, the operator and the WRA may reasonably regard the landfill as hydraulically interconnected.

Solid wastes

7.13 Operational methods should be chosen to maximise the dispersion and mixing of special wastes within the bioreactive wastes.

7.14 Typically, a special solid waste or sludge should be deposited at the base of a tipping face, and spread in a thin layer. Municipal or other non-hazardous waste should then be placed over it. This

- ► helps to distribute the special waste evenly through the landfill
- ► reduces the risk of creating massive deposits of special waste that may form hydraulic barriers to percolating leachate.

7.15 Spreading into thin layers may be easier to achieve for some solid wastes than for others. If the physical form of the waste is such that satisfactory dispersion within the biodegradable waste cannot be achieved, the operator may be sensible to consider pre-treating the waste to make it more dispersible.

- The WRA should not accept difficulties with the physical form of the waste as an excuse for failing to achieve even dispersion of wastes.

Liquid wastes

7.16 Liquid wastes are sometimes deposited directly into a depression at the foot of a solid waste tipping face. This produces a reasonably even distribution of liquid waste throughout the landfill. Its disadvantages are

- ► that it is only manageable for small quantities of liquid
- ► that, for certain types of waste (such as acids), it may be an inappropriate technique however small the quantities.

7.17 Where annual liquid quantities exceed ~5,000t/a, trenches excavated into previously tipped areas are the most common arrangement. In this way, liquid waste operations can be kept entirely separate from solid waste operations.

Trench design

7.18 Trenches may be of various designs and specifications. They are an important part of site civil engineering works. They should be designed and constructed to a high standard.

7.19 Typically, trenches would be ~1-2m wide and ~3m deep. The length would depend on the rate of input.

- Liquid application rates of ~20,000m^3/ha.a, or ~2m/a, have been sustained at trench densities of 200 linear metres of 2m wide trench per hectare.

7.20 Trenches may be

- open, for relatively low hazard, non-odorous wastes, or
- covered, and possibly filled with tyres, for more odorous or hazardous wastes such as strong acids or alkalis. In covered trenches, the liquid is discharged through a slotted pipe (usually 20-30cm diameter) protruding from the trench.

PRECAUTIONS

7.21 The liquid waste disposal areas must be carefully designed to

- ensure the safety of everybody on site
- minimise the movement of tankers on site.

7.22 Precautions taken to prevent accidents during the discharge of wastes into trenches vary; they should generally be similar to those used at any facility for the treatment/disposal of special wastes.

7.23 The operator should use the working plan to specify physical safeguards. They may include

- the placing of fencing, bunds and warning signs all around the trenches
- the provision of wind-socks, emergency showers and first aid equipment.

Some current practice

7.24 At the majority of landfills receiving liquid wastes, discharge is made directly from the delivery tanker discharges the waste direct to the disposal area.

7.25 At many sites, the permitted liquid waste types are restricted to those which are chemically compatible with each other: only one disposal area is needed. At some larger sites, centralised waste reception facilities are provided: liquid waste is divided into categories, with one disposal area for each category.

7.26 At one site, small volumes of odorous wastes are deposited directly into a short, covered trench; but large volumes of chemically compatible, non-odorous waste, are discharged into common reception sumps, then pumped across the site to a longer, open trench. This system greatly reduces the movement of tankers on the site: the majority remain within a dedicated industrial waste reception area at all times.

Staffing and control of operations

7.27 All large co-disposal sites should have written operating procedures governing the management and supervision of co-disposal operations.

7.28 Some sites have specialised teams dealing only with co-disposal. Most major sites employ technical staff on site: these are most usually chemists with a degree, an HNC or an equivalent qualification.

7.29 The site licence may require that a chemist be on site whenever special wastes are being received or deposited; but the need for this depends on the size of the operation and the range of wastes being deposited. The chemist's main role in controlling co-disposal operations is in the inspection, sampling, checking and testing of incoming waste.

7.30 Traffic control, supervision and marshalling of the disposal operations themselves are normally carried out by trained operatives. They should have been trained in

- safety
- first aid
- the use of breathing apparatus.

They will often have attended specialised courses on landfill and hazardous waste management.

7.31 It is usual practice for a trained site employee to accompany any vehicle taking special waste to the disposal area; he follows a formal radio contact procedure throughout, with each contact being recorded by a traffic controller.

- As a result of such precautions co-disposal has an excellent safety record.

Health and Safety aspects are considered in greater detail in appendix F.

Leaching and reactor requirements

General requirements

7.32 Operational methods should be designed to

- ► optimise the performance of the landfill as a reactor
- ► accommodate leachate management activities.

They should remain compatible with other constraints, such as safety, the protection of controlled waters (e.g. leachate head restrictions) and litter control.

7.33 The most important requirements are

- to encourage a high level of biological activity
- to encourage the early establishment of methanogenic conditions and to maintain them
- to provide a minimum retention time of 1 year
- to allow even leaching of all the solid wastes so that soluble contaminants and degradation products are flushed out at rates consistent with the requirements of sustainable development. This is likely to mean that average hydraulic retention times should be no greater than 5 years.

7.34 These requirements are most likely to be met if leachate recirculation is practised from an early stage in the life of the site. Leachate recirculation is more conveniently carried out in completed or capped areas; but

- operations can and should be so planned that leachate recirculation can also be carried out at a high rate in, or close to, active tipping areas.

Biological activity

7.35 The moisture content of wastes, and the rate of moisture flux, are important controls on

- ► the rapidity with which a waste mass achieves methanogenic conditions
- ► the subsequent rate at which stabilisation progresses.

7.36 Experience suggests that many degradable wastes, as deposited in landfills, are too dry to promote biological activity. Until the waste has taken up an additional 10%[25] of water, the landfill will not produce leachate or establish methanogenic conditions.

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[25] by weight

7.37 During the filling of landfill cells, additional water may enter the wastes as rainfall. This does not justify the rapid infilling of cells (which are often sized on the basis of water balance calculations) and the subsequent progressive capping and restoration. The practice may

- delay the onset of methanogenesis
- limit the rate at which nutrients are supplied to the microbial population
- limit the rate at which leached materials are flushed from the wastes.

7.38 Experience in Denmark and Germany suggests that if, about six months before the main operation, the operator places an uncompacted basal layer[26] of fresh[27] municipal waste, he will promote the rapid onset of methanogenic conditions. At landfills where this technique has been used, the production of acetogenic leachate has been avoided.

Avoidance of hydraulic barriers

7.39 The use of low permeability materials for daily cover interferes with the free flow of leachate. The operator should adopt measures to avoid this problem; the WRA should ensure through licence conditions that he does so.

7.40 Under some circumstances, a landfill can be operated without any daily cover. This is common practice in several other European countries.

7.41 If the WRA nevertheless accepts the operator's view that daily cover is indispensable, the WRA should ensure

either that the cover is removed before placement of the next lift of waste
or that a high permeability material[28] is used.

7.42 The reported degree of success in removing daily cover varies; but this may simply be due to variations in the training and experience of plant operators.

- In the most successful examples, the cover material, and a small amount of solid waste, are bladed off into loose bunds, to form a new operational area. No attempt is made to re-use the cover material.

- The bunds thus formed may present some resistance to lateral movement of leachate and gas; but if they are vertically discontinuous they are less likely to cause substantial interference.

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[26] 1-2 metres

[27] or aerobically degraded (composted)

[28] $K > 10^{-4}$m/s

7.43 Several commercial alternatives to conventional daily cover have been developed. None has yet been used to any significant extent in the UK; but the WRA should not for that reason reject their use. They include

- sprayed chemical foams (e.g. urea-formaldehyde) which collapse when a new lift of waste is deposited

- sprayed paper pulp, prepared using paper separated from the waste stream.

7.44 A site haul road in prolonged use may become highly compacted, and thus form a barrier to leachate flow. The operator and the WRA should consider whether this is is likely to happen. If it is, the operator may arrange to rip highly compacted surfaces, or even to re-excavate disused haul roads.

Waste pre-treatment

7.45 Pre-treatment of wastes, both municipal and special, may affect the performance of the landfill as a reactor, in ways that may be either beneficial or detrimental.

7.46 If municipal waste is shredded, and pre-sorted to remove plastics, its hydraulic characteristics will improve: this will promote more uniform conditions in the landfill, and more uniform leaching. Shredding, by decreasing particle size, may also increase the rate of refuse degradation. This can go too far: the excessive production of fatty acids may inhibit the establishment of methanogenesis.

7.47 Waste recycling initiatives may substantially change the make-up of the municipal waste stream by removing some of its existing components. The change is not necessarily beneficial to co-disposal.

- In some landfills in continental Europe, the residual wastes have been difficult to compact, and unable to retain moisture for any length of time.

- Rain from heavy storms has reached leachate abstraction points within hours: the landfills have not become methanogenic.

Under such circumstances, and even with the judicious use of recirculation, the operator might find it difficult or impossible to provide conditions and retention time adequate to co-disposal.

7.48 Pre-treatment of liquid wastes is now practised at some co-disposal landfills. It typically provides the range of processes used at other commercial pre-treatment centres:

- acid/alkali neutralization
- precipitation of heavy metals
- oil/water separation
- soil/liquid separation.

7.49 After pre-treatment, the aqueous effluent and the dewatered solids are co-disposed separately.

- The aqueous effluent may present a more uniform, less inhibitory feedstock to the landfill biomass, and represent a net benefit.
- The dewatered solids could, subject to the results of a leaching test, contain less available metal than in the untreated liquid waste, and likewise represent an additional benefit.
- Conversely, if the dewatered solids were improperly deposited, they
    - could cause the inefficient dispersal of heavy metals and other such components of the refuse mass
    - could form barriers to leachate flow.

Chapter 8

Leachate management

Introduction

8.1 Among the chief advantages of controlled co-disposal should be

- that its leachate is of much the same quality as that from a municipal waste landfill
- that no additional difficulties affect leachate treatment and disposal.

This chapter considers various aspects of leachate management at co-disposal landfills, including water balance calculations, recirculation, monitoring, and treatment.

8.2 Generally applicable guidance on leachate management is given in WMP 26B and WMP 26C. This chapter supplements that guidance by noting special considerations for co-disposal.

8.3 At any landfill that relies upon biological reactions and the flushing out of pollutants to stabilize the deposited wastes, leachate management is of central importance.

8.4 A co-disposal site must, crucially, be run as a flushing bioreactor; but in many practical aspects, leachate management at a co-disposal site resembles leachate management at a site receiving only municipal waste.

8.5 Preventing the formation of leachate is **not** an objective of water balance control at a co-disposal site: it would conflict with the necessity for

- leaching of solid industrial wastes and
- mixing of the leached components with the bioreactive wastes.

8.6 What is important is

- that the leachate management plant and capability are adequate to the rate of leachate generation
- that the rate of leachate generation and the rate of leaching of solid wastes, however brought about, are compatible with the objective of sustainable development.

Water balance calculations

8.7 Water balance calculations should be no different in principle from those at other landfills, **except** that the operator, in calculating liquid inputs, must allow for

- liquid wastes
- sludges with a particularly high moisture content.

8.8 As with other landfills, water balance calculations have two main purposes:

1. to size the cells so as to avoid practical difficulties caused by excess leachate during the operational phase
2. to predict and interpret actual leachate volumes and leachate levels, during the operational and after-care periods, so as to size and manage the leachate removal and leachate treatment capability.

8.9 A simple water balance calculation should be undertaken twice yearly, as a check on whether any increase in free liquid storage is occurring within the site. This calculation should be of the form

Free Leachate Retained = Inputs - [outputs + absorptive input]

or, $Lo = [ER + LIW] - [LTP + aW]$

where Lo = free leachate retained

ER = Effective Rainfall — This may need to be modified to account for surface run-off, especially after capping.

LIW = Liquid Industrial Waste — including any surplus water from sludges with a high moisture content

LTP = Discharge of leachate off-site

a = unit absorptive capacity of wastes

W = weight of absorptive waste.

Leachate recirculation

Benefits

8.10 Recirculation of leachate has been practised, to varying degrees, for the following reasons:

- to encourage early establishment and maintenance of methanogenesis. A high moisture content and the movement of moisture have both been shown to promote methanogenesis
- to develop a more uniform quality of leachate, so that the design and operation of treatment and disposal facilities is easier
- to minimise dry zones in the wastes, which could otherwise remain largely undegraded for many years
- to take up absorptive capacity and reduce fluctuations in leachate flow rate.
- to promote enhanced evaporative losses by surface spraying
- to provide temporary storage of short-lived peak flow rates, allowing treatment facilities to be designed for flows closer to average values.

Problems and concerns

8.11 Problems experienced during recirculation have occasionally led to the practice being abandoned or even prohibited. They include

- surface flooding caused either by irrigation rates being locally too high or by formation of inorganic solid layers (e.g. iron pan)
- health concerns and exacerbation of smells, as a result of spray drift, especially with acetogenic leachates
- break-outs of perched leachate from the side-slopes of landfills, exacerbated by the presence of compacted or low-permeability layers within the wastes.
- clogging of sub-surface recirculation systems
- at some landfills receiving predominantly inorganic waste (e.g. incinerator ash sites), extremely high concentrations of dissolved salts.

Requirements for sustainable landfilling

8.12 Recirculation at high rates may become necessary in order to achieve stabilization and flushing of municipal waste and co-disposal landfills within an acceptably short time-scale.

8.13 Flushing by up to 7 Bed Volumes of water may be needed to flush out soluble pollutants, particularly NH_3-N, to acceptable concentrations.

- A hydraulic retention time of less than 5 years would be needed to achieve this within a 30 year period.
- Irrigation rates of around 2,000mm/a or even more, would be needed at many landfills: this greatly exceeds effective rainfall in most parts of the UK, and could only be achieved by recirculation.

8.14 The purpose of recirculation would also be to leach co-disposed solid wastes so that their components can interact with the biodegradable wastes.

8.15 Because high rates of recirculation may cause the accumulation of inhibitory NH_3-N concentrations, the operator may need to incorporate partial treatment to nitrify ammonia.

- In situ denitrification may reduce leachate treatment costs. At co-disposal sites the operator must also monitor any build-up of dissolved salts caused by leaching from solid co-disposed wastes.
- The need to control dissolved salt concentration in leachate may limit the recrculation rate. The feasible rate will depend on the rates of
  - influx of clean percolation and
  - leachate discharge.

Recirculation engineering

8.16 Recirculation systems should be designed and constructed to high standards of engineering. As yet, insufficient engineering effort has been applied to the optimisation of their design.

8.17 The recirculation techniques used to date include both surface and sub-surface systems.

Surface systems

8.18 Surface application typically uses rain-guns or slotted pipe. In at least one case a central-pivot agricultural irrigator has been used.

Sub-surface systems

8.19 Sub-surface systems have the advantage that they can be placed entirely below the final cap, allowing them to continue in use after the cessation of disposal operations.

8.20 Standard 80mm diameter, slotted agricultural drainage pipes may be installed into made ground such as completed landfills.

- ► Agricultural drainage practice typically spaces drain-lines at between 10 and 20 metres apart in order to achieve even drainage.
  - In the absence of operational experience, it may be assumed that a similar spacing would be effective for leachate recirculation lines. This equates to about 700 metres of pipe per hectare.
- The pipes are generally installed at slightly below 1 metre depth by mole plough, with a gravel bed placed around each pipe.
- The operator should consider whether, to minimise the development of zones of preferential infiltration close to input points, to the detriment of other more remote sections of the irrigation system, each line of irrigation pipe should be fed separately.

Development of the technique

8.21 Some practical aspects of recirculation at high rates will need further development if it is to become widely used.

8.22 Drainage blankets have usually been designed for the rates of percolation reaching them naturally through operational or capped areas of landfills. Typically these rates vary from 50 mm/a to 500 mm/a. The ability of drainage layers to maintain low leachate heads during recirculation at 2,000 mm/a or more would require investigation.

8.23 The design of leachate re-injection systems to achieve uniform distribution within the landfill also needs further development. Trenches filled with tyres or other drainage media can transmit sufficient leachate but may still leave significant dry zones between the trenches.

8.24 Landfill operation techniques may need to be altered to minimise the hydraulic barriers created by compacted layers and daily cover.

- The WRA should ensure that, while licence conditions provide adequate environmental protection, they do not prevent innovation and development.

Leachate monitoring

8.25 The basic principles of leachate monitoring at co-disposal landfills remain similar to those presented in WMP 26D (DoE, 1994c).

8.26 At a co-disposal site leachate monitoring should

- reliably indicate quality changes over time, with an acceptable degree of confidence
- reliably indicate level changes over time, with an acceptable degree of confidence
- render more effective the control of on-site processes (such as leachate recirculation and leachate treatment systems) by providing data
- provide feedback control over waste inputs by confirming that leachate quality is as expected and hence that landfill processes are working as expected
- demonstrate compliance with relevant site licence conditions.

More monitoring points than usual

8.27 A co-disposal site may need more leachate monitoring points per cell, so that the operator can monitor the effects of special/difficult wastes on the processes occurring within the waste.

More determinands than usual

8.28 It may be necessary to analyse leachates from co-disposal sites for a greater range of determinands than those given in WMP 4 (1994a) and WMP 26D (1994c). The analysis would include additional components of the co-disposed wastes: it should confirm

- that they are **not** present in the leachate, and
- that the leachate is no different from that found at household waste landfills.

Leachate quality

8.29 Co-disposal leachate should achieve a quality similar to those of municipal waste leachate.

8.30 Surveys show that this can be done.

- Data from five co-disposal sites were obtained during the co-disposal research review (KNOX, 1989).
- Data from a further 9 co-disposal sites and 21 municipal waste sites were obtained during a more recent review of leachate composition (ROBINSON, 1994).
- The results are compared in table 8.1.

8.31 All the co-disposal sites in these reviews were methanogenic.

- The municipal sites included some which were still acetogenic, and some where control of water inputs was relatively poor.
- As a result, the municipal sites exhibited slightly higher average concentrations of organics and lower concentrations of dissolved solids than the co-disposal sites.

8.32 Average concentrations of some heavy metals were slightly higher at the co-disposal sites; but for most, the difference was not statistically significant. Concentrations of phenols, organotin and adsorbable organic halogens (AOX) were very similar at both types of site.

8.33 More significant quality differences have occurred at some landfills where waste inputs have been insufficiently controlled.

- These anomalies have included elevated concentrations of pesticides and heavy metals, both of which could lead to difficulties in the treatment and discharge of the leachate.

Such anomalies can be avoided if the operator and the regulator follow the guidance in this document.

Leachate treatment

Biological methods work

8.34 Co-disposal leachate treated like leachate from a municipal waste landfill should satisfy the pre-conditions for discharge to sewer or surface waters. The treatment methods described in WMP 26B and WMP 26C are equally applicable to co-disposal sites.

8.35 Biological treatment methods suffer no inhibition or loss of performance at properly controlled co-disposal sites.

- Nitrification of ammonia, which is sensitive to inhibition, was investigated in detail at the UK's largest co-disposal site, at Pitsea, Essex. The kinetics of the process were found to be similar to those reported for nitrification in domestic sewage, municipal waste leachates, and other wastewaters.

- Full-scale biological treatment has been undertaken successfully at Pitsea since 1985, and is also undertaken at several other large co-disposal sites.

Planning for failure in leachate quality

8.36 The operator and the regulator should consider the effects of any failure of the performance or control of the landfill: such a failure might cause the leachate to contain substances that could interfere with treatment processes, or cause the effluent to exceed discharge limits.

8.37 The leachate monitoring régime and the site management procedures should be designed to

- provide advance warning of any such occurrence
- allow adequate time for remedial measures to be taken within the landfill.

8.38 The operator should consider

- whether to build additional safeguards into the leachate treatment plant particularly if the discharge is direct to surface waters rather than to sewer

- whether to provide storage to retain leachate for several days between the treatment plant and the discharge point. The need for this would depend on the sensitivity of the receiving water

- whether to prepare contingency plans for adding unit processes such as activated carbon adsorption to remove trace organics, or lime addition to precipitate heavy metals.

8.39 The facility to return insufficiently-treated leachate to the landfill is important at a co-disposal site, just as it is at a municipal landfill. The operator should therefore have good reason if he decides not to provide it.

Table 8.1 Comparison of leachate quality at municipal and co-disposal landfills
concentrations in mg/l unless otherwise stated

To be read in conjunction with paragraphs 8.29 to 8.33

	municipal waste landfills (n = 21)		co-disposal landfills (n = 14)	
Parameter	**mean**	**std. dev.**	**mean**	**std. dev.**
pH	7.22	0.47	7.38	0.31
conductivity (μS/cm)	6686	4125	11518	3953
chloride	1039	745	2131	745
sulphate (as SO_4)	144	207	113	100
NH_3-N	438	393	665	320
COD	3275	7304	2366	3002
TOC	733	1345	661	634
BOD	689	1366	674	1290
Na	725	548	1513	826
K	444	327	603	386
Ca	293	360	156	57
Mg	139	97	176	100
Fe	71	147	16	16
Mn	2.6	5.5	0.79	0.88
Zn	0.39	0.54	0.82	1.67
Cu	0.03	0.012	0.06	0.039
Ni	0.09	0.081	0.15	0.068
Cr	0.07	0.041	0.12	0.138
Cd	<0.01	-	<0.02	-
Pb	0.10	0.053	0.11	0.060
Sn	6.7(1)	12.5	2.4	2.98
B	2.7	2.1	17.2(2)	35.1
V	0.54	0.60	1.18	0.91
As (μg/l)	6.5	5.7	13.8	13.5
Hg (μg/l)	<0.1	-	<0.1	-
total cyanide (as CN)	<0.05	-	0.09(3)	0.11
monohydric phenols (as phenol)	0.43	0.99	0.45	0.63
organotin(4) (μg/l)	0.34	0.34	0.24	0.34
AOX (μg/l)	232	231	340	251

(1) Sn results in municipal waste sites are affected by two extreme values of 42 and 47 mg/l. Without these the concentrations are: mean 2.75mg/l, standard deviation 2.57mg/l.

(2) Boron results for co-disposal sites are affected by one site with 116mg/l. Without this the results are: mean 4.8mg/l, standard deviation 3.34mg/l.

(3) 75% of the co-disposal sites had total cyanide below the detection limit of 0.05mg/l.

(4) Organotin was detected in only 50% of the sites. Values at the detection limits of 0.02-0.2μg/l were included in calculating the averages shown in the table.

Chapter 9

Completion

Applying to surrender a site licence

9.1 This chapter reinforces the guidance contained in Waste Management Paper 26A: it indicates some special considerations which apply to the completion of a co-disposal landfill site.

9.2 A licence holder who is considering applying to surrender a licence for a co-disposal landfill should first assess whether there is likely to be sufficient reliable information about the site to satisfy the WRA and its consultees.

- ► If the site is well characterised and clearly in a stable condition, the licence holder could proceed with the application.
- ► If not, the operator needs to decide whether to carry out the work needed to demonstrate completion.

In practice, a properly designed monitoring scheme, incorporating regular review and routine liaison between the site operator, the WRA, the water pollution control authorities and other relevant authorities should indicate to all parties that the conditions appropriate to completion are approaching.

9.3 The period needed to achieve landfill completion can be optimised by appropriate management of the operations at the site, including

- ► leachate recirculation
- ► homogenization of biodegradable wastes
- ► deposition of co-disposed waste evenly within the bioreactive wastes.

Earlier chapters of this WMP provide guidance.

Completion criterion

9.4 The criterion for deciding whether a landfill site may receive a Certificate of Completion is that

- the WRA must be satisfied that the condition of the land
    - ► is **not** likely to cause pollution of the environment **and**
    - ► is **not** likely to cause harm to human health.

9.5 The WRA should articulate this criterion in practical terms. It should apply a set of concentration limits for gas and leachate.

9.6 The limits should be related to the risk of gas or leachate reaching sensitive targets. This will depend on site-specific factors.

- To demonstrate that the completion criterion has been met, the operator may need to make an assessment of the risk. Guidance on the factors to be taken into account in assessing that risk are contained in WMP 26A.
- The operator may wish to use the risk assessment methodology currently being developed for the Department of the Environment and the NRA (GOLDER ASSOCIATES, 1995). He is not obliged to do so.

Relevant factors for co-disposal landfills

9.7 To determine whether or not a co-disposal site meets the completion criterion, the following factors should be assessed:

- the trends in the quality of leachate present
- the trends in the flow and quality of gas
- the potential for polluting leachate or gas to be generated in future
- the potential for leachate or gas to reach sensitive targets
- the possibility of physical instability of the waste or retaining structures
- the presence of residues of co-disposed wastes which could present a hazard in the future.

9.8 The most important way in which a co-disposal landfill site might cause pollution or harm to human health is by release of pollutants in gas or leachate. In particular, it is possible that solid co-disposed wastes could continue to leach contaminant concentrations in excess of target values.

Solid special wastes

9.9 At some landfills, the WRA will wish to have from the operator an assessment of the state of the solid special wastes in the landfill.

9.10 The operator will then use leaching tests on recovered samples

- ▸ to ascertain whether sufficient leaching has occurred, and
- ▸ to confirm that the solids are no longer capable of leaching contaminant concentrations in excess of target values.

Details of a draft leaching test protocol are given in appendix B.

Information requirements

Site history

9.11 To demonstrate completion, historical information on the construction, operation and monitoring of the site is particularly useful.

9.12 For new sites, regulated under the Environmental Protection Act 1990, this should present no difficulty. Licence conditions should ensure that such information has been collected throughout the pre-operational, operational and post closure periods.

9.13 Many co-disposal landfills, however, will be those previously operated under the licensing provisions of the Control of Pollution Act 1974 (COPA). Few will have had monitoring systems designed from the outset with the completion procedure in mind. More detailed investigations may be required for completion.

- At such a site the operator, in consultation with the WRA, should make an early review of the monitoring programme (see WMP26D, forthcoming) to ensure that sufficient data are being collected to demonstrate completion of the site.

9.14 The operator and the WRA should pay particular attention to monitoring carried out after any landfill gas and leachate control measures have been curtailed: this is when changes in the conditions within the wastes are likely to occur.

9.15 Where leachate recirculation systems remain in use at co-disposal landfills,

- they should be suspended in advance of complete system shut down to allow the leachate levels within the site to equilibrate.

9.16 The WRA should examine monitoring data during this period before determining, in liaison with the operator, the point at which completion monitoring should commence.

9.17 The WRA should consider whether any additional data are needed, and discuss with the operator how to obtain them. This may include drilling boreholes and taking and analysing samples.

Completion monitoring

9.18 All sampling programmes and data assessment exercises should be designed in a statistically valid way.

9.19 For co-disposal landfill, one of the most important programme design factors will be the heterogeneity of the waste. Samples taken from a co-disposal landfill site may be spatially more variable than at a household waste site, because of the variable nature of the wastes deposited and the methods of deposition.

- ► This is particularly likely at COPA sites and sites where leachate recirculation has not been practised.

The number of sampling points, and the sampling frequency, should be chosen to provide the necessary degree of confidence in the results.

9.20 The minimum number of sampling points, the frequencies of sampling and the lists of determinands required at this stage of co-disposal landfill management are indicated in other Waste Management Papers[29]. The rest of this chapter discusses considerations specific to co-disposal landfills.

Number of leachate and gas sampling points

9.21 One of the key principles of the co-disposal landfill is the optimisation of its performance as a bio-reactor. Leachate is the medium which brings about intimate contact between industrial waste components and the decomposing refuse. Leaching of the solid wastes is essential.

9.22 The recommended minimum number of monitoring points may be too small to allow the operator to monitor the landfill's effectiveness in leaching co-disposed wastes.

- In assessing the site's need for additional monitoring points, the WRA should give due consideration to
    - ► the hydraulics of the site
    - ► the degree of control exerted over waste input and segregation at the site.

Duration of monitoring

9.23 By definition, a co-disposal landfill should be operated as a flushing bioreactor process: considerable data and process knowledge should have accumulated before the completion monitoring period.

- Extended periods of further completion monitoring are therefore unlikely to be necessary.

- For sites that are already well characterised, WMP 26A recommends two years of completion mnitoring. That may well be enough for a co-disposal landfill.

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[29] WMP 4 (1994a), *Licensing of Waste Management Facilities*; WMP 26A (1993), *Landfill Completion*; WMP 26D (1994c), *Landfill Monitoring*

Frequency of sampling

9.24 Information on leachate recirculation, leachate quality and gas quality is likely to be more extensive for a co-disposal landfill than a municipal waste landfill.

- If sufficient reliable data have been available in historical records and assessments, the WRA and the operator may regularly review, and where necessary amend, the frequency of monitoring; this may be done even before the initiation of a more formal completion monitoring phase.

Selection of determinands

9.25 With one exception, the completion-monitoring suites in WMP 26A are consistent with those recommended for the routine monitoring of co-disposal landfills. The exception is that

- additional determinands, not included in the suites but known to have been present in the wastes deposited at the site, may need to be added to the appropriate list.

9.26 Conversely, if the WRA is satisfied that a particular determinand is no longer of value, it can be omitted.

Gas potential

9.27 Gas flow data and gas quality data up to the completion monitoring phase should indicate a well-stabilised system.

- This should be supported by evidence that the waste mass within the site has been uniformly wetted and consistently leached.

9.28 The WRA may have doubts about this aspect of site stabilisation. If so, it should consider requiring the operator to assess the gas potential of the solid wastes[30] before it allows him to progress to the completion monitoring stage.

9.29 In a co-disposal site there is a greater chance that, locally, inhibition of refuse degradation may have been caused by the presence of special wastes.

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[30] using methods outlined in WMP 26A; see also BIOTAL,1992.

Solids sampling

9.30 A rational solids sampling and monitoring strategy may be defined only if there is a clearly stated objective. In the context of a co-disposal site, the objectives of sampling might include

- to determine the mean concentration of a specified heavy metal in the most contaminated cubic metre of waste within a site
- to determine the depth-averaged concentration of phenolics
- to determine the proportion of the site, by volume, containing a specific contaminant at concentrations above a specified trigger level.

The WRA should select objectives that are sensible and achievable. It should consider the levels of precision and confidence to be achieved: this specification of the degree of uncertainty dictates how much sampling is needed.

9.31 Where a landfill contains one type of waste, or a mixture of wastes that is known to be compatible and synergistic, the WRA should **not** require invasive testing as part of the completion monitoring phase **except** under special circumstances.

- ▸ Appendix A of Waste Management Paper 26A discusses the inputs, processes and outputs from landfills. It concludes that leachates and landfill gas measurement are generally the most reliable integrated measure of the conditions within the waste mass at municipal waste landfills.

9.32 At a site where the operator has co-disposed different classes of waste, the WRA may wish to have practical assurance of the status of the solid wastes. The sampling locations should then be based on detailed site records, if available. These should simplify the problem of devising a statistically sound sampling programme and minimise the resulting expenditure.

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Appendix A

Technical overview of co-disposal

UK research into co-disposal

A1. An initial programme of research into the landfilling of hazardous wastes was undertaken from 1973-78 and the results published in the 'Brown Book' (DoE, 1978). Further research then continued during the late 1970s, throughout the 1980s and into the 1990s. In 1989 the results of a comprehensive research review were published (KNOX, 1989). The research studies undertaken up to that time are summarized in table A1.

Table A1. Summary of Research into co-disposal, 1973-1989

'BROWN BOOK' PROGRAMME, 1973-78

DETAILED SITE INVESTIGATIONS AT 20 LANDFILLS

Sites were chosen to represent common geological settings and 19 categories of industrial waste. Most of these subsequently became the subject of individual Waste Management Papers.

Site investigations typically involved drilling boreholes inside and outside the landfill, followed by sampling and analysis of waste materials, leachate and groundwater.

LABORATORY SCALE CO-DISPOSAL RESEARCH

- Leaching of pollutants from industrial wastes, including dewatered metal hydroxide sludges, phenolic lime sludges, acid tars, and arsenic sludges and slags.
- Dissolution of mercury from battery cells in refuse.
- Neutralization of acids and acid tars by refuse.
- Hydrolysis and degradation of cyanide.
- Adsorption of phenols by refuse.
- Anaerobic fermentation of phenols in domestic refuse leachate.
- Equilibration of added tritium, with moisture content of refuse.

LYSIMETER CO-DISPOSAL RESEARCH (200 LITRE TO 8m^3 IN SCALE)

- Adsorption and evaporation of dry-cleaning solvents from refuse.
- Adsorption and degradation of phenols by refuse.
- Co-disposal of cyanide heat treatment waste.
- Co-disposal of metal hydroxide sludges.
- Co-disposal of oil/water emulsion.

ATTENUATION STUDIES

- Four 50 m^3 *in situ* lysimeters were developed and instrumented in the Lower Greensand; they were irrigated with different synthetic leachates: a 'heavy metal' leachate, an 'organic' leachate and an 'anionic' leachate.

- Monolithic 650 litre cores of undisturbed Lower Greensand, Lower Chalk, and alluvial gravel were irrigated under laboratory conditions with various synthetic leachates.

- 30 m^2 undisturbed in situ zones of Lower Chalk and river gravels were irrigated with synthetic leachate. Effects on groundwater were monitored using a series of boreholes.
- Re-compacted laboratory-scale columns (300 ml - 24 litres) of Lower Greensand were irrigated with various synthetic leachates.

CO-DISPOSAL RESEARCH, 1979-1989

FIELD INVESTIGATIONS

- Leachate and groundwater monitoring were continued at several of the 20 landfills which had been investigated in the *'Brown Book'* programme.
- Microbiological studies were undertaken at one site to correlate bacterial numbers with groundwater contamination levels.
- A privately-funded field examination was carried out into the effects of prolonged acid disposal at one full-scale landfill, with the installation of leachate monitoring points, landfill gas sampling, and the sampling and analysis of sludges and sediments.
- Privately-funded research into the concentrations and attenuation of heavy metals close to liquid co-disposal areas was undertaken at another full-scale landfill.
- A mass balance approach was applied to five full-scale landfills, during the research review, to assess their performance as reactors. The sites comprised three major liquid waste co-disposal landfills, one major solid waste co-disposal landfill and one mixed special waste landfill. The assessment compared waste input quantities and characteristics with rainfall inputs and leachate output quantities and characteristics.

LYSIMETER STUDIES

- Operation of earlier 200 litre lysimeters examining phenol co-disposal was continued.
- Large (300 m^3) outdoor lysimeters were constructed to examine co-disposal of: gasworks spent oxide waste containing complexed cyanide; mineral acids containing heavy metals; phenolic lime sludge.
- New 200 litre lysimeters were commissioned, to examine co-disposal of heavy metals.

LABORATORY STUDIES

- A leaching test procedure was developed for assessing loading criteria for industrial waste co-disposal.
- Methodology for the sampling and testing of the acid buffering capacity of domestic refuse was developed.
- Anaerobic degradation of phenol was studied in methanogenic domestic refuse columns.
- Removal of heavy metals from solution by domestic refuse of different ages was studied, under acid conditions.

A2. The collated research unequivocally demonstrated a capacity for decomposing refuse to

- degrade phenols and a wide range of other organics, including some aromatic compounds
- degrade free and complexed cyanide
- neutralise acids
- immobilise many heavy metals from solution.

Degradation rates and removal capacities for all four groups of chemicals were comparable with those obtainable in other types of anaerobic reactor. In research studies the efficiency of the refuse as a reactive medium was maximised by

- saturated conditions, with leachate recycle
- established methanogenesis
- elevated temperatures, which promote high rates of biological activity
- long hydraulic retention time.

Phenols

A3. Complete methanogenic fermentation of phenols to CH_4 and CO_2 was achieved in several studies. The degradation rate for phenol in methanogenic refuse was comparable with that in anaerobic digesters, ranging from 5 to 50g/m^3.d, with no evidence of nutrient deficiency or toxic inhibition. Lower removal rates were obtained in non-methanogenic conditions, at ambient temperatures, and where no saturated zone existed nor leachate recycle was practised. The loading rate recommended in chapter 5 has been set at the lower end of the range observed under methanogenic conditions.

A4. Tolerance to shock-loading was observed, possibly due to the temporary reduction of inhibitory concentrations by reversible adsorption on refuse components. At excessive loading rates inhibition did occur. Phenol degradation failed before inhibition of methanogenesis, so the occurrence of elevated phenol in leachate would be an early warning sign of possible inhibition.

A5. The results with several phenols suggested that a general capability of degrading aromatic compounds exists in methanogenic refuse, similar to that found in conventional anaerobic digesters. Degradation of some chlorinated pesticides has been observed in other studies.

Cyanide

A6. Both free and complexed cyanides were readily degraded in anaerobic refuse. The removal rates in methanogenic refuse were at least as great as in conventional digesters and ranged from ~1 to 19g CN/m^3.d. The degradation pathways have not been clearly established and it is possible that in refuse, several mechanisms operate simultaneously, some purely chemical and some biological.

A7. The fact that both free and complexed cyanides were degraded, with no evidence of a difference in rate suggests there is no justification for applying different loading rate controls to the two forms. The loading limit recommended in chapter 5 is set at the lower end of the observed range.

Acids

A8. A wide variety of inorganic acids was readily neutralized by refuse obtained from a wide variety of sources within the UK. For most acid/refuse combinations the buffering capacity was in the range 100-1000eq/t. The values were affected by both the source of the refuse and the source of the acid. There was some evidence that biological processes in landfills led to the regeneration of buffering capacity, up to several thousand equivalents/tonne. However, the loading limit recommended in chapter 5 has been set at the lower end of the above range.

Heavy metals

A9. Numerous studies have demonstrated the immobilisation of metals by refuse. The loadings immobilised were often similar to the background levels of metals found in refuse, typically in the range 100-1000g/tonne. At these loadings there was no evidence of inhibition of methanogenesis. The loading limit given in chapter 5 is set at the lower end of this range for most metals. For some metals, lower loading limits are given because of their greater toxicity and/or mobility.

A10. Some studies showed that metals were immobilized even under strongly acidic conditions. This and other evidence led to the conclusion that the initial removal mechanism may involve adsorption or ion-exchange phenomena, rather than precipitation as hydroxides, carbonates or sulphides, even though these may be the most thermodynamically stable forms in methanogenic refuse.

A11. Acetogenic conditions or the addition of acids sometimes led to the release of heavy metals from the refuse. Elevated levels often persisted after neutralization of pH, taking many months to return to background levels. For this reason a minimum hydraulic retention time of 1 year is recommended.

Landfills as reactors

A12. Four major UK co-disposal sites were studied and all were found to perform efficiently as reactors. Inputs contained a wide range of special wastes, while leachate quality remained virtually indistinguishable from methanogenic municipal waste leachate.

A13. The co-disposal sites studied had many common characteristics which contributed to their successful operation as reactors: all four were containment sites, with a saturated zone exceeding 30% of the waste volume, hydraulic retention times exceeding 2 years, and established methanogenesis.

A14. Applied organic loading rates were in the range 1-10gTOC/m^3.d. These are low rates compared to conventional digesters and are at or below typical carbon metabolism rates during refuse decomposition.

A15. Heavy metal loadings were of a similar order to background concentrations in refuse, and within the ranges immobilised in experimental studies.

Areas of uncertainty and on-going research

Heavy metals

A16. The review concluded that some aspects of heavy metals co-disposal required further research, in particular the effect which organic ligands may have on metal immobilization, and the speciation and long-term stability of the immobilized metals. Studies into speciation and the effects of ligands have now been carried out on behalf of the Department of the Environment (JUGGINS ET AL., 1993).

A17. The strong ligand EDTA caused a significant reduction in the immobilization of Pb, Cu and Zn. It had only a slight effect on Ni and Cd and virtually no effect on Cr. Most added metals were bound as oxides or forms of equal or greater chemical stability, leached only under fairly extreme conditions. A significant proportion of added Ni and nearly all of the added Cd were in less strongly bound, ion-exchangeable forms. The added metals were distributed primarily among four components of municipal waste: paper, fines (including some putrescibles), plastic and textile.

A18. The effect of organic ligands, and the important role of waste components which would be degraded with time, confirmed that research is needed on both the long-term fate of immobilized metals and the anaerobic degradability of industrially-used ligands.

A19. The research should also consider the effects of changing redox conditions on metal stability.

Anaerobic bioassay test

A20. The review identified a need for an Anaerobic Bioassay Test (ABT) which could be used to assess the fate and impact of individual compounds or wastes when co-disposed, particularly for organic compounds which may not have been previously investigated.

A21. A draft test protocol has now been developed by the Public Health Laboratory Service, Porton, and is reproduced in appendix C.

A22. An information database of anaerobic degradability data is needed for a range of common waste types and common organic waste constituents. The existence of this database could help to reduce the amount of testing needed on individual wastes.

Leaching

A23. Leaching tests will be needed to evaluate the behaviour of co-disposed solid wastes. A draft protocol for a test is included as appendix B: it has not yet been subjected to practical evaluation.

A24. The requirements of the test, specifically for co-disposal, need to be further defined and the test itself subjected to validation trials, taking into account the many leaching tests developed already for other regulatory purposes in Europe and around the world. An evaluation of the test is now under way.

Incinerator ash

A25. The quantity of incineration residues requiring land disposal is expected to rise in the next few years. The quantity of ash from sewage sludge incineration is expected to be in the range 130-200,000t/a by the year 2000 while the quantity of ash from incineration of municipal and commercial wastes may rise to over 400,000t/a. Locally, these residues could form a significant loading if co-disposed. Research has been under way in recent years at the Environmental Safety Centre, Harwell, to investigate the co-disposal of fly ash and bottom ash from incineration of both MSW and sewage sludge (Scott et al., 1993a; 1993b).

Biological indicators

A26. Assessing the biological health and level of activity in co-disposal sites is presently reliant upon parameters such as temperature, gas production, leachate pH, leachate BOD/COD ratio and analysis of leachate for mobilised special waste components. More specific diagnostic monitoring techniques would be of great benefit. Work has begun at the Public Health Laboratory Service to try to develop a DNA probe to assess methanogenic activity for this purpose.

Landfill hydraulics

A27. The hydraulics of landfilled wastes are poorly understood but often appear to be affected by short-circuiting and by barriers to flow. There is a need for better knowledge of the hydraulic characteristics of wastes under different conditions, including co-disposal sites, and for the development of engineered techniques for leachate recirculation at high rates. These are required so that landfills can be operated effectively as flushing bioreactors.

Appendix B

The development of a leaching test to determine co-disposal loading rates

B1. A contract has been let by DoE to provide a protocol for determining the leaching characteristics of materials intended for co-disposal. It is based on the draft protocol suggested by Knox (1992)[31], and will make use of procedures in the latest draft of the CEN compliance test (CEN/TC292/WG2, draft 10) for determining the specific leaching characteristics of waste materials.

B2. Commonly co-disposed materials such as filter cakes, contaminated soils and fragmentiser residue (frag) are being tested; the leachates produced are being analysed for priority pollutants, according to the type of sample. The leaching data derived from this protocol will help WRAs and operators to determine suitable loading rates for co-disposed wastes.

B3. The test being developed under this contract will supply loading data for the co-disposal of wastes, while the CEN test is a compliance test; but common procedures should be used where possible. The steering group for the contract will decide upon details such as liquid/solid ratios before the programme of analysis begins. Results will be reviewed and reported on by the end of February 1995. A methodology will then be produced a sresources allow.

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[31] Knox K (1992): 'The role of research in controlling co-disposal in the UK'. In: proc Harwell Waste Management Symposium on New Developments in Landfill. AEA, Harwell, 33-52.

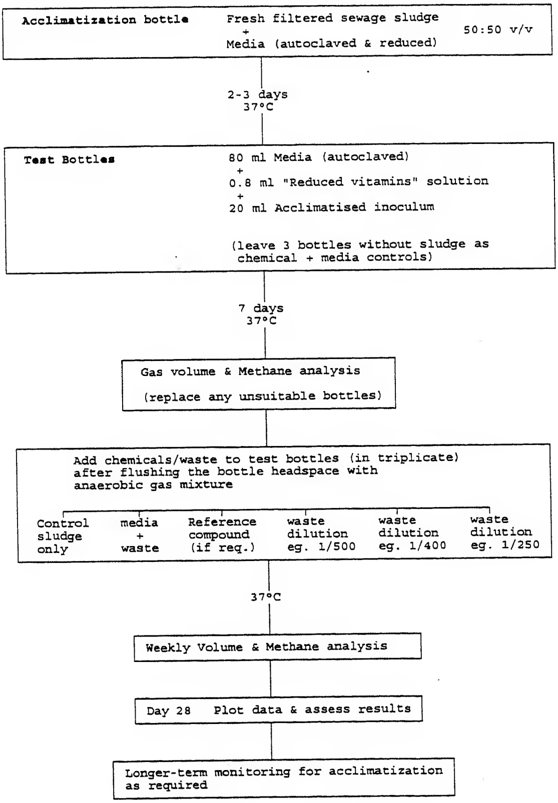
Appendix C

Anaerobic bioassay test protocol

Standard Operating Procedure

I. The Liquid Test System

A series of serum bottles (in triplicate) containing acclimatised sewage sludge are challenged with different concentrations of chemical waste. The volume of gas, and the percentage headspace methane, produced by each bottle is then monitored on a weekly basis for a period of 28 days. The schedule is as follows;


Acclimatization bottle
Fresh filtered sewage sludge
+
Media (autoclaved & reduced)
50:50 v/v
2-3 days
37°C
Test Bottles
80 ml Media (autoclaved)
+
0.8 ml "Reduced vitamins" solution
+
20 ml Acclimatised inoculum
(leave 3 bottles without sludge as chemical + media controls)
7 days
37°C
Gas volume & Methane analysis
(replace any unsuitable bottles)
Add chemicals/waste to test bottles (in triplicate) after flushing the bottle headspace with anaerobic gas mixture
Control sludge only
media + waste
Reference compound (if req.)
waste dilution eg. 1/500
waste dilution eg. 1/400
waste dilution eg. 1/250
37°C
Weekly Volume & Methane analysis
Day 28 Plot data & assess results
Longer-term monitoring for acclimatization as required

Standard operating procedure: liquid test system

NB. All procedures involving the handling of the test chemicals or sewage sludge culture are carried out in a fumehood with suitable protective clothing including gloves and safety glasses.

Due care should be taken when handling the cultures of anaerobic microorganisms keeping them under an anaerobic atmosphere, between 20 - 40°C and incubating in the dark.

Methanogen growth medium

The growth medium used is based on that used by Shelton and Tiedje (1984) and should be prepared with analytical grade reagents and contains (per litre distilled water):

KH_2PO_4	0.27 g/l
K_2HPO_4	0.35 "
$NaHCO_3$	3.0 "
Na.Acetate	2.5 "
Na.Formate	2.5 "
Yeast extract	2.0 "
Trypticase	2.0 "
Ferrous sulphate	2.0 mg/l

Mineral salts solution (1) use 10 ml/l

Trace metals solution (2) use 1 ml/l

Redox indicator: Resazurin stock solution (1.0 mg/ml)- use 1 ml per litre of medium

Mineral salts (1)	NH_4Cl	53.0 g/l
	$CaCl_2.2H_2 0$	7.5 "
	$MgCl_2.6H_2 0$	10.0 "
	$FeCl_2.4H_2 0$	2.0 "
Trace metals (2)	$MnCl_2.4H_2 0$	0.5 g/l
	H_3BO_3	50.0 mg/l
	$ZnCl_2$	50.0 "
	$CuCl_2$	30.0 "
	$NaM0_4.2H_2 0$	10.0 "
	$CoCl_2.6H_2 0$	0.5 g/l
	$NiCl_2.6H_2 0$	50.0 mg/l
	Na_2SeO_3	50.0 "

Adjust medium to pH 7.0 with 5M HCl. Add the vitamins and reducing agents after the medium has been autoclaved and just before the bottles are to be inoculated.
Store resazurin, dithiothreitol and vitamins (Balch et al., 1979), at 4°C.

Reducing agents	Dithiothreitol	0.4 g/l
	Cysteine HCl	0.175 g/l
Vitamins	Biotin	2 mg/l
(stock solution	Folic acid	2 "
use 10 ml per	Pyridoxine HCl	10 "
litre of medium)	Thiamine HCl	5 "
	Riboflavin	5 "
	Nicotinic acid	5 "
	D,L-Pantothenic acid	5 "
	Cyanocobalamin	0.1 "
	p-Aminobenzoic acid	5 "
	Lipoic acid	5 "

Preparation of sewage sludge inoculum

Sewage sludge should be collected from a properly functioning anaerobic sludge digestor, in one litre bottles (Merk Ltd). The bottles should have a wide neck, an air-tight seal and be constructed from high density polyethylene or a similar material which can expand. Glass bottles must not be used. The bottles are filled to within one centimetre of the top and sealed tightly (SCA, 1988). The sewage sludge should ideally be used as soon as possible after collection. The sludge is filtered, under an atmosphere of N_2:H_2:CO_2 (80:10:10, v/v), through mesh (500 μm mesh size) to remove coarse fibres and debris.

Procedure **Day 1**

1. Decide on the number of different concentrations or dilutions of chemicals to be tested. Allow 3 serum bottles (160 ml total volume - Chromatography Services), per concentration, 6 bottles as controls (3 sludge only and 3 chemical only).

   N.B. It is advisable to use more than 3 sludge only bottles for the controls, to reduce the potential problem of any control bottles failing.

2. Calculate the volume of methanogen growth medium required.

   Allow at least 90 ml medium per bottle (80 ml for the "Test bottle" + 10ml or more for the "Acclimatisation bottle").

   For example: in an experiment with five test concentrations, sludge controls reference chemical and media/chemical controls (all in triplicate), you need 24 "Test bottles" plus three spares (total 27 bottles). You, therefore, need (27 x 80 ml) + (27 x 10 ml) = 2430 ml medium for the "Test bottles" and "Acclimatisation bottle", so make 2.5 litres of medium.

3. Prepare the medium without the reducing agents and the vitamins.

4. Number the bottles and write the experimental test number on each bottle.

5. Transfer sufficient medium into a Duran bottle ("Acclimatisation bottle") so that there will be enough culture to inoculate each of the "Test bottles" (allow for a 20 ml inoculum of the 50:50 v/v medium:sludge acclimatised culture per "Test bottle") eg. for 27 "Test bottles" you need (27 x 10 ml medium) = 270 ml, so add 300 ml medium to the Duran bottle.

6. Transfer 80 ml of medium to each serum bottle ("Test bottles").

   NB. The volume must be accurate since any unnecessary variation at this stage will make the final results less reliable.

7. Flush the headspace of all the bottles with anaerobic gas mix (N_2:H_2:CO_2; 80:10:10, v/v), before sealing with rubber septa (Aldrich Chem. Co. Ltd). Secure the septa tightly with aluminium seals (Aldrich Chem. Co. Ltd), using a crimper (Chromatography Services).

8. Autoclave the bottles for 20 min at 121 °C. (Autoclave the "Acclimatisation bottle" first if space is limited.)

9. While the bottles are being autoclaved prepare sufficient "Reduced vitamins" (vitamin solution + dithiothreitol + cysteine hydrochloride) to reduce the medium in the "Acclimatisation bottle" (allow 1 ml per 100 ml of "Methanogenic growth medium").

10. The "Reduced vitamins" should be added while the "Acclimatisation bottle" is still warm and the headspace is being flushed with anaerobic gas mix. The medium should turn light yellow/clear as it becomes reduced. Cool the bottle to 37 °C. The other bottles should be cooled and then stored at 4 °C.

11. Add an equal volume of the filtered sewage sludge to the medium in the Duran bottle while flushing the headspace with anaerobic gas mix. Close the lid tightly. Incubate the "Acclimatisation bottle" in the dark at 37 °C for 2-3 days to acclimatise the culture to the test conditions.

Day 2-3

12. Warm the test bottles to the incubation temperature (37 °C). Prepare sufficient "Reduced vitamins" to reduce the medium in the test bottles (0.8 ml per 80 ml medium).

13. If paper or any other inert solids are to be added (in order to provide surfaces for adsorption), they should be added now, making a note of the volume displacement.

14. Remove crimp caps, add "reduced vitamins" (0.8 ml), to each "Test bottle" containing 80ml of medium, while flushing the headspace with anaerobic gas mix via a wide bore needle (0.8 x 40 mm), hooked over the top of the bottle under the septum. (This removes any residual oxygen and equalises the pressures between the bottles).

    NB. Any bottles that are not going to have sewage sludge added must be handled first, using aseptic technique to avoid contamination.

15. When all the test bottles have been reduced, place them in a 37 °C incubator for at least 30 minutes before inoculation. (If they are cool or are to be left for a long time then wrap a small piece of aluminium foil round the top of the bottles to prevent the loss of the septa while the bottles are warming-up).

16. Inoculate each "Test bottle" with 20 ml of acclimatised sewage culture from the "Acclimatisation bottle" using a 10 ml pipette. Keep the culture well mixed using a magnetic stirrer. Gas both the "Acclimatisation bottle" and the "Test bottle" with anaerobic gas mix during this procedure. Leave 3 bottles without any sewage culture as chemical/medium controls.

17. Reseal the bottles with butyl rubber septa and crimp the tops with aluminium seals. Swirl the bottles to ensure even mixing. Place the bottles in the dark, in a 37°C incubator.

18. The "Acclimatisation bottle" is no longer required, it should be thoroughly cleaned.

1 week after inoculation

19. Record the gas volume produced, followed by % headspace methane of all the "Test bottles" (except the chemical controls which only have a single reading at the end of the test period), see "Gas volume and percentage methane readings" for the procedures. Also make a note of the peak area of the pure methane standard (Phase Separations Ltd).

20. Calculate the % headspace methane from the peak areas of the traces, using standard curve equations. (Make a methane standard curve using gas mixtures of known methane concentration prepared in crimp top serum bottles).

21. Calculate the number of moles of methane from the volume and % headspace methane readings (see "Calculations").

22. Calculate the coefficient of variance (Rees, 1985), for the moles of methane for each triplicate (see "Calculations").

    On day 7 bottles should have a coefficient of variance of less than 5%. Any bottles with either low or high gas production should be replaced with spares.

    If all the bottles are giving very low readings, ie. producing less than 15 ml volume and 15% headspace methane, reject these bottles and repeat the experiment with fresh sewage sludge.

Day 14 - Addition of chemicals

If making up solutions of reference compound see 23).
If using waste material directly see 24).

23. If pure compounds or mixtures of poorly water-soluble compounds (e.g. halogenated solvents), are going to be tested, the required series of stock solutions are prepared in acetone.

    Acetone is used as the carrier solvent so that poorly water-soluble compounds can be added more easily. Acetone was shown to be the least toxic/stimulatory of the solvents tested and had negligible effect when added at 100 µl per 100 ml culture.

    NB. It is the final concentration in the culture which is important, so the stock solutions need to be prepared so that a 100 µl addition to 100 ml of culture will give the desired final concentration.

24. If a waste effluent is to be evaluated, different volumes of the waste should be added (in triplicate) to give various dilutions up to 1/100.

    NB. The headspace volume in the calculations should be changed for additions of 1 ml or more of waste.

25. Sterile controls (i.e. no inoculum) should contain the highest concentration of compound to be tested. Readings should be taken on these bottles on day 28 after incubation at 37°C. These serve as controls for abiotic gas production.

26. Add 100 µl of the required stock solution of chemical to the appropriate bottles.

To add the chemicals:

a. remove the aluminium crimp cap

b. flush the headspace for a minimum of 30 seconds with anaerobic gas mix using a gas needle (hooked over the top of the bottle under the septum). This removes residual methane before the addition of reference and test chemicals. The headspace of the control bottles are flushed in the same way. This provides a clearer picture of the inhibition by these chemicals on the rate of methane production.

c. add the required volume of chemical (under the surface of the liquid to reduce volatilisation) using a "Finpipette" (Anderman and Co.).

d. remove the gassing needle and quickly reseal with the septum.

e. recrimp the bottle and swirl to mix before returning the bottle to the 37°C incubator.

27. Routinely take gas volume and methane readings once a week. Check the bottles regularly to make sure that an excessive gas pressure has not built up, causing the septum to swell. If this happens take volume and methane readings to release the pressure.

N.B. At high concentrations some solvents such as hexane may affect the septa.

28. After 28 days incubation, plot the data (moles of methane produced vs. time) for the test and controls with no added chemical waste.

29. After 28 days the frequency of the readings can be reduced to fortnightly readings if required.

NB. There tends to be an increase in the variation between replicates from around day 28.

30. At the end of the experiment liquid cultures containing no waste must first be autoclaved (121°C for 30 min.), before being emptied down the drain with copious amounts of water. Liquid cultures containing high concentrations of chemicals/waste need to be stored in an appropriate container for specialist treatment. Discard septa.

Thoroughly clean all glassware before re-use.

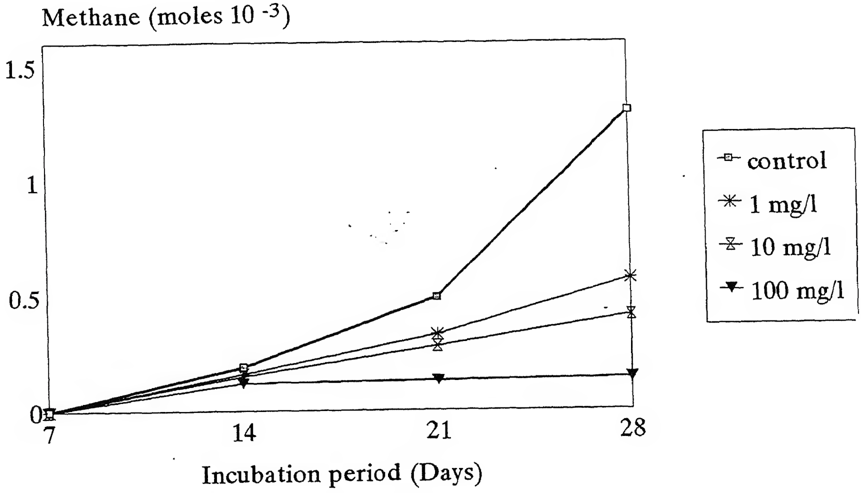
System validation using reference compounds

Reference chemicals can be included in each experiment as internal controls, to check the validity of the liquid system. For example, 1,2-dichloroethylene (10 mg/l) should reduce methane production by approximately 50% relative to sewage sludge controls (Fig. 1), whilst phenol (100 mg/l) should reduce it by approximately 30%, over the 28 day incubation period (Fig. 2).

Fig. 1

Effect of 1,2-Dichloroethylene in liquid system

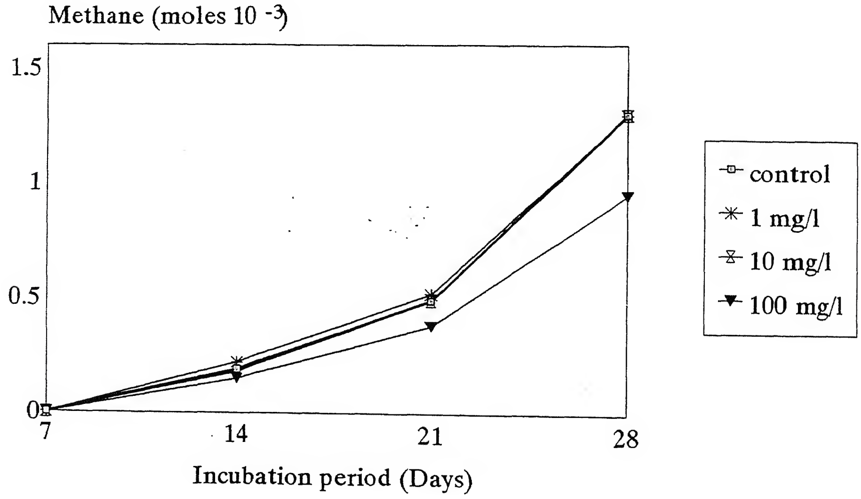
(Methane produced per week)



Addtions made after headspace flushed on day 7

FIG. 2

Effect of Phenol in liquid system
(Methane produced per week)



Addtions made after headspace flushed on day 7

Gas volume & percentage methane readings

Gas volume measurement

Gas volume readings should be carried out in a fume hood.

The headspace gas volume in serum bottles is measured by the displacement of the piston in a glass syringe (Kernick and Son Ltd).

Use a 100 ml glass volumetric syringe, lubricated with water and held lightly in a horizontal position by a clamp and stand. A needle (20 gauge), is attached to the syringe via a 10 cm piece of tubing.

If possible take the volume readings at 37°C. If not take the bottles out of the incubator in triplicate (to maintain temperature). Insert the needle through the septum of the bottle. Any gas pressure is then released and the volume of gas produced can be read. When the piston of the syringe has stopped moving, pull it slightly further out and it will return to its equilibrium position when released. With very gassy bottles it is sometimes necessary to stop the barrel at about 80-100 ml. Remove the needle from the bottle, record the volume, vent the syringe before repeating the process. The plunger is lubricated with distilled water as necessary.

Methane analysis

Headspace gas samples are obtained using a 1 ml syringe, inserted through the septum of the bottle after the gas volume has been measured. This analysis is performed isothermally (100°C), using a Flame ionisation detector (FID) gas chromatograph fitted with a glass column (1.5 m length and 4 mm internal diameter) packed with silica gel. Oxygen-free nitrogen is used as the carrier gas (40 ml/min). The injector temperature is 100°C and the detector temperature is 250°C. G.C. traces are obtained with a Hewlett Packard HP 3390A integrator.

Samples (0.5 ml) of headspace gas from each of the bottles are injected immediately after removal from the bottles. The retention time for methane is approximately 0.8 min. Analysis should take about 2 min per sample.

Ethane and Ethylene may also be detected by this method but with longer retention times of approximately 2 and 4.5 min respectively.

If no ethane or ethylene is being produced; the samples can be injected at 30-40 second intervals, provided that care is taken to ensure the samples are run in strict numerical order. If very little or no methane is expected from some bottles it is better to do these on separate runs.

Calculations

Number of moles of methane are calculated using the Ideal Gas Equation;

$$PV = nRT \qquad \text{Therefore} \qquad n = PV/RT$$

The number of moles of methane produced = % methane x n / 100.

Where n = number of moles of gas
P = atmospheric pressure = 1.013×10^5 Nm^{-2}
V = [volume produced + headspace volume] x 10^{-6}

R = the gas constant = 8.31 J mol^{-1} K^{-1}
T = (temperature °C + 273);K

The **Coefficient of Variance** is defined as:

100 x standard deviation/mean

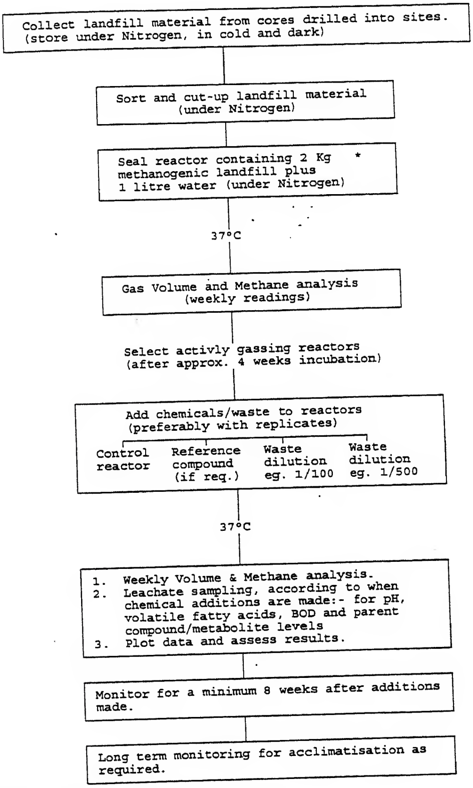
and is expressed as a percentage. This is used to compare the variability in two sets of data when there is an obvious difference in magnitude in both the means and the standard deviations. The standard deviation, for a small number of samples, is calculated using the formula:

$$s=\sqrt{[\Sigma(x-\bar{x})^2/n-1]}$$

Where s = standard deviation
x = individual sample
$\bar{x}$ = replicate mean
n = number of replicates

II. Solid-Phase, Model Landfill System

A flow-diagram for the schedule is shown below.


Collect landfill material from cores drilled into sites.
(store under Nitrogen, in cold and dark)
Sort and cut-up landfill material
(under Nitrogen)
Seal reactor containing 2 Kg methanogenic landfill plus 1 litre water (under Nitrogen) *
37°C
Gas Volume and Methane analysis
(weekly readings)
Select activly gassing reactors
(after approx. 4 weeks incubation)
Add chemicals/waste to reactors
(preferably with replicates)
Control reactor
Reference compound (if req.)
Waste dilution eg. 1/100
Waste dilution eg. 1/500
37°C
1. Weekly Volume & Methane analysis.
2. Leachate sampling, according to when chemical additions are made:- for pH, volatile fatty acids, BOD and parent compound/metabolite levels
3. Plot data and assess results.
Monitor for a minimum 8 weeks after additions made.
Long term monitoring for acclimatisation as required.

* For variations on composition, see main text.

NB. All procedures involving the handling of the test chemicals or landfill material are carried out in a fumehood with suitable protective clothing including gloves and safety glasses.

Preparation of landfill material

Landfill material is obtained from actively-gassing landfill sites, during routine drilling operations, at a number of different depths (2-20 m). The landfill material is quickly sealed in air-tight plastic sacks and transported promptly to the laboratory. The refuse is hand-sorted to remove large pieces of material, for example, glass and metal, and with reference to the average compositional analysis of municipal waste (Wigfull & Gregory, 1991). The remaining landfill material is mixed whilst flushing the contents of the plastic sack with oxygen-free nitrogen before being resealed. Landfill material can be stored this way for several months at 4°C and retain an active methanogenic population.

Procedure

1. Drill three holes, as indicated in Fig. 1, in each of the 3 or 4 l plastic pots (Philip Harris Scientific), to allow the insertion of three two-way taps (Cole Parmer Instruments Ltd), and seal them in place using "Araldite" glue.

2. Place a 500 g layer of washed gravel at the bottom of each pot (enough to cover the entrance to the lower two-way tap).

3. Fill each pot with approximately 2 kg of suitably mixed gassing landfill material (Wigfull & Gregory, 1991), whilst flushing with nitrogen gas. Only compact the material sufficiently to fit it into the pot.

4. Add another layer of washed gravel on the top before adding tap water (1200 ml) to each reactor, whilst flushing with nitrogen gas.

5. Seal the lids with silicone rubber sealant (RS Components Ltd), to ensure that the reactors are airtight.

6. Attach an empty gas collection bag (2 or 5l, Plysu Ind. Ltd), onto the top sample port and open the tap.

   Ensure the other two taps are closed.

7. Number each of the reactors and incubate at 37°C in the dark.

8. When the reactors are equilibrated (over-night), empty the gas collection bag (to zero the volume readings).

9. Once or twice a week (more often for very active material), measure and record the volume of gas and % headspace methane produced (see "Gas volume and methane readings").

10. To take the methane reading, close the taps to the gas collection bag, remove the bag and take a 0.5 ml sample of the gas using a sealable syringe. Measure the methane concentration, as described above. Also make a note of the reading of the pure methane standard.

11. The volume readings should be carried out at 37°C, using either a gas syringe or by displacement of water in an inverted measuring cylinder, according to the level/degree of inflation of the gas collection bag (see "Gas volume and methane readings"). Replace the gas collection bag before re-opening the taps.

12. Calculate the % headspace methane from the peak areas of the traces (from a Hewlett Packard 3390A integrator), after reference to a standard curve using gas standards of known methane concentration (Phase Separations Ltd), prepared in crimp top serum bottles.

13. Calculate the number of moles of methane from the volume and % headspace methane readings (see "Calculations").

Leachate Sampling

14. Leachate samples should be taken at least once a month or when additions are made to the reactors. The leachate is analysed for pH, volatile fatty acids (see "Volatile fatty acid analysis") and B.O.D. (SCA, 1983).

15. Draw off a leachate sample (30 or 40 ml, depending on the size of the pot), using a plastic syringe via the bottom tap. Store leachate samples in plastic universal bottles at -21 °C. Close the bottom tap and open the side port to replace the sample taken for analysis with the equivalent volume of tap water or chemical waste.

Addition of Chemicals

16. Once the reactors have become methanogenic (50 % headspace methane is normally achieved within 2 to 3 weeks of incubation, depending on source of landfill material), additions of test chemicals or waste can be made, using a plastic syringe, via the side port. Changes in gas production or leachate quality can be compared with control reactors (in duplicate at least).

    If making up solutions of pure compounds see 17.
    If using waste material directly see 18.

17. If pure compounds which are poorly water-soluble are going to be tested the required series of stock solutions are prepared in acetone.Acetone is used as the carrier solvent so that poorly water-soluble compounds can be added more easily. Acetone was shown to be the least toxic/stimulatory of the solvents tested and had negligable effect when added at 0.1% v/v (final reactor concentration).

    The total volume added should be 30 or 40 ml (1ml of acetone containing chemical + tap water).

18. If a waste effluent is to be tested, different volumes i.e. between 1 and, 30 or 40 ml of the waste (depending on size of reactor), are added to each of the reactors (in duplicate). The total volume added should be either 30 or 40 ml (the difference is made up with tap water).

19. Control reactors (i.e. no test chemical added) should have the same volume of leachate drained and the equivalent volume of tap water added, at the same time as the test reactors, via the bottom and side tap, respectively.

20. Add the chemicals, using a syringe, via the side tap of the reactor (make a note of the concentrations and dates of the additions for each reactor).

21. Check the reactors daily, to make sure that excessive gas pressure has not built-up in the gas collection bags.

22. Monitor the reactors weekly for gas volume and methane production. The pH, volatile fatty acids, BOD and parent compound/metabolite levels in the leachate are monitored at least once a month or according to the type of waste to be added.

23. After 60 days incubation, following the addition of the test chemical, plot the data (moles of methane produced vs. time) for the test and controls with no added chemical waste.

24. These reactors may be maintained at 37°C for an extended period of time (6 months to a year), for further additions and/or to monitor adaptation to chemicals, as required.

Gas volume and methane readings

Methane analysis

Headspace gas samples are obtained using a 1 ml syringe, inserted into the top tap of the reactor. This analysis is performed isothermally (100°C), using a Flame ionisation detector (FID) gas chromatogram fitted with a glass column (1.5 m length and 4 mm internal diameter) packed with silica gel. Oxygen-free nitrogen is used as the carrier gas (40 ml/min). The detector temperature is 250°C and the injector temperature is 100°C. G.C. traces are obtained with a Hewlett Packard HP 3390A integrator.

Samples (0.5 ml) of headspace gas from the reactors are injected immediately after removal from the reactors.

The retention time for methane is approximately 0.8 min. Analysis should take about 2 min per sample.

Ethane and Ethylene may also be detected by this method but with longer retention times of approximately 2 and 4.5 min, respectively.

If no ethane or ethylene is being produced; the samples can be injected at 30-40 second intervals, provided that care is taken to ensure that the samples are run in strict numerical order. If very little or no methane is expected from some reactors it is better to do these on separate runs.

Gas volume measurement

Gas volume readings should be carried out in a fume hood.

The headspace gas volume in reactors can either be measured from the displacement of the piston in a glass syringe, or for larger volumes (greater than 100 ml), the displacement of water from an inverted measuring cylinder. If possible carry out the volume readings at 37°C, i.e. in a constant temperature room.

If a 100 ml glass volumetric syringe is used, lubricate the syringe with water and hold it in a horizontal position using a clamp and stand. Attach the gas collection bag to the syringe via a three-way junction with taps. Close the exhaust tap and draw the contents of the gas collection bag into the syringe to measure the volume. Close the tap on the collection bag and expel the gas into a fumehood. Repeat as necessary.

For large volumes, expel the contents of the gas collection bag into an inverted gas cylinder (2 litres), full of water and record the volume of displaced water.

Vent the contents of the measuring cylinder within a fumehood before repeating the process.

Calculations

Moles of methane are calculated using the Ideal Gas Equation;

$$PV = nRT \qquad \text{Therefore} \quad n = PV/RT$$

The number of moles of methane produced = % methane x n / 100

Where n = number of moles of gas
P = atmospheric pressure = 1.013×10^5 Nm^{-2}
V = [volume produced + 1 ml headspace volume] $\times 10^{-6}$
R = the gas constant = 8.31 $J\ mol^{-1}\ K^{-1}$
T = (temperature °C + 273);K

NB.An accurate headspace value is not available, so a 1 ml value is used to standardise.

Volatile fatty acid analysis

The composition of volatile fatty acids in the leachate can be determined by gas-liquid chromatography. A 1 ml sample of the leachate is taken and acidified using 100 μl of 5M HCl in an Eppendorf tube. This is then centrifuged for one minute in an Alderman 5414 Eppendorf centrifuge to remove particulate matter. The supernatant is transferred to a clean Eppendorf tube and should be shaken vigorously just prior to injection to ensure that a homogeneous sample is used. A 0.5 μl sample of this is injected into a Pye Unicam PU 4500 Gas Chromatograph fitted with a 1.5 m glass column (4 mm internal diameter) packed with 10% FFAP. Injector temperature is 250°C and flame ionization detector temperature 250°C. The column is run isothermally at 150°C. Carrier gas is nitrogen (flow rate 40 ml/min) and sample run time is 20 minutes. Traces obtained with a Hewlett Packard HP 3390A integrator are compared to standard curves of the individual acids (acetate, propionate, isobutyrate, butyrate, isovalerate, valerate and hexanoate are used at 1 - 100 mM), obtained under the same run conditions.

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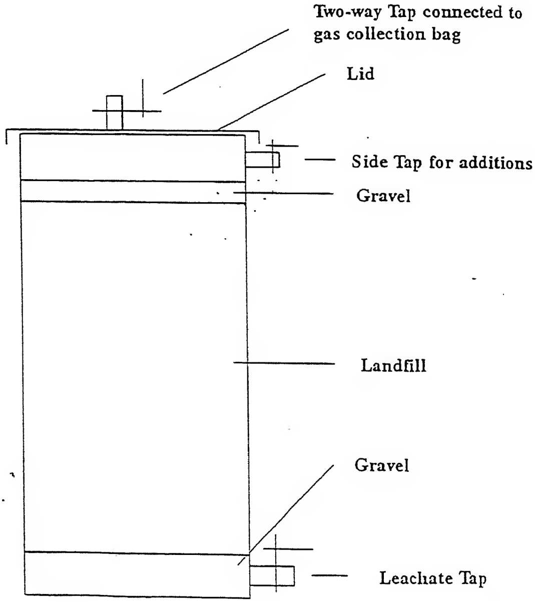
FIG 1

Landfill Reactor Design



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Appendix D

Licence conditions for a co-disposal site

This appendix provides a checklist of topics which a WRA should consider when drafting a site licence for a co-disposal landfill. It considers those aspects which are specific to co-disposal but does not include more general details common to all landfills. A more generally applicable checklist for all types of landfill is given in Waste Management Paper 4 (DoE, 1994).

The points listed in this appendix are given for guidance only. A WRA may decide that some do not require a specific licence condition. These may be topics to be dealt with during site preparation, but not subsequently; or they may be most appropriately covered in the Working Plan.

A WRA may also decide that additional topics, not detailed here, are necessary at a particular landfill. The checklist consists of key words, grouped under four main headings

D1	Site evaluation and preparation
D2	Leachate management
D3	Controls over waste inputs and operations
D4	Monitoring of licence controls.

D1. Site evaluation and preparation

Location
Groundwater vulnerability
Risk assessment
NRA Groundwater Protection Policy
Surface water vulnerability
Natural containment
Engineered containment
Reception facilities for special wastes
- vehicle waiting area
- laboratory facilities

D2. Leachate management

Leachate collection system design
Leachate recirculation system design
Phasing plan
Site hydraulics
Water balance predictions
Control of water inputs
Leachate disposal arrangements
On-site leachate treatment
Leachate treatment safeguards and contingency plans

D3. Controls over waste inputs and operations

Waste classification system
Criteria for waste acceptance
Positive lists of allowed wastes
Negative list of forbidden wastes
Non-component loading limits
Component loading limits
Approval/notification procedures
Level 1, 2 and 3 waste testing by operator

Staffing levels
Staff training and qualifications
Safety equipment
Emergency procedures
Site operating procedures
Operational areas
Operational methods
Daily cover

Leachate monitoring
Gas monitoring
Leachate level/volume control
Water balance updates
Leachate recirculation methods
restoration specification

D4. Monitoring of licence controls

Inspection visits
Random sampling by WRA
Monthly waste inputs
Monthly accounting of loading limits
Records of waste locations
Monitoring data for gas, leachate level and quality
Liaison/review procedures for waste inputs and operations
Environmental control/leachate management review procedures

Appendix E

Classification system for chemical components of special wastes

Table E.1 Concentration Codes for Chemical Constituents of Industrial Wastes

Source: Waste Management Paper No 2 (1976), Waste Disposal Surveys, Coding Table 2

CODE	CONCENTRATION
A	Trace
B	≤ 1 ppm
C	≤ 5 ppm
D	≤ 10 ppm
E	≤ 100 ppm
F	≤ 0.1 %
G	≤ 1 %
H	≤ 3 %
J	≤ 5 %
K	≤ 10 %
L	≤ 15 %
M	≤ 20 %
N	≤ 30 %
P	≤ 40 %
Q	≤ 50 %
R	≤ 60 %
S	≤ 70 %
T	≤ 80 %
U	≤ 90 %
V	≤ 100 %
W	= 100 %
X	major component
Y	minor component
Z	unclear

CLASSIFICATION OF DIFFICULT WASTES

Type of Waste	Groups and sub-groups	Group code	Sub-group code
A Inorganic acids	Hydrochloric acid	A10	
	Sulphuric acid	A20	
	Nitric acid	A30	
	Chromic acid	A40	
	Phosphoric acid	A50	
	Hydrofluoric acid	A60	
B Organic acids and related compounds	Aliphatic acids eg formic, acetic and oxalic acids		B11
	Aromatic acids eg benzoic, phthalic acids		B12
	Acid anhydrides eg acetic, phtahalic anhydrides		B13
	Acid chlorides eg acetyl, benzoyl chlorides		B14
	Sulphonic acids		B15
C Alkalis	Alkali metal oxides and hydroxides, calcium oxide, proprietary alkaline cleaners	C10	
	Sodium and/or potassium hydroxides or oxides		C11
	Calcium oxides		C12
	Ammonia	C20	
	Calcium hydroxide		C91
	Sodium and/or potassium carbonates		C92
D Toxic metal compounds	Cadmium	D10	
	Mercury	D20	
	Lead	D30	
	Arsenic	D40	
	Copper		D91
	Zinc		D92
	Barium (water soluble forms)		D93
	Thallium		D94
	Nickel		D95
	Vanadium		D96
	Silver		D97

Type of Waste	Groups and sub-groups	Group code	Sub-group code
E Non-toxic metal compounds	Ammonium salts		E91
	Titanium		E92
F Metals (elemental)	Alkali, alkaline earth and other hazardous metals	F10	
G Metal oxides	Hazardous oxides	G10	
	Cadmium oxide		G11
	Beryllium oxide		G12
H Inorganic compounds	Cyanides	H10	
	Sodium and potassium cyanides		H11
	Soluble complex cyanides		H12
	Ferro and ferricyanides		M13
	Sulphides, selenides, tellurides and arsenides		H21
	Oxidizing compounds	H30	
	Hypochlorites and chlorites		H31
	Chlorates, perchlorates, bromates, iodates, periodates, persulphates and permanganates		H32
	Peroxides		H33
	Chromates		H41
	Fluorides, Silicofluorides, borofluorides		H42
	Arsenates and arsenites		H43
	Carbides and acetylides		H91
	Borates		H92
	Nitrites		H93
	Nitrates		H94
J Other inorganic materials	Asbestos	J10	
	Slag including boiler and flue cleanings	J20	
	Mineral processing wastes	J30	
	Silt and dredgings	J40	
	Water (contaminated)	J50	

Type of Waste	Groups and sub-groups	Group code	Sub-group code
K Organic compounds	Hydrocarbons (not included in M)	K10	
	Aliphatic hydrocarbons		K11
	Aromatic hydrocarbons		K12
	Phenols, analogues and derivatives	K20	
	Chlorinated phenols and analogues		K21
	Peroxides	K30	
	Halogenated cleaning compounds	K40	
	Trichlorethylene		K41
	Perchloroethylene		K42
	Trichlorethane		K43
	Trichlorotrifluoroethane		K44
	Halogenated compounds excluding cleaning compounds	K50	
	PCBs and analogues		K51
	Organo metallics	K60	
	Tetra ethylead		K61
	Tetra methylead		K62
	Nitrogen, sulphur or phosphorus-containing compounds	K70	
	Amines and amides		K71
	Nitro compounds		K72
	Nitriles		K73
	Isocyanates		K74
	Other organo nitrogen compounds		K75
	Organophosphorous compounds		K76
	Organosulphur compounds		K77
	Oxygen containing organic compounds	K80	
	Esters		K81
	Ethers		K82
	Aldehydes and ketones		K83
	Alcohols		K84
	Chelating compounds		K91
	Phthalates		K92

Type of Waste	Groups and sub-groups	Group code	Sub-group code
L Polymetic materials and precursors	Precursors, monomers and products of incomplete polymerization	L10	
	Epoxy resins (not finished products)		L11
	Polyester resins (not finished products)		L12
	Phenol-formaldehyde resins (not finished products)		L13
	Finished products and manufacturing scrap	L20	
	Polyurethane		L22
	Scrap rubber (including tyres)	L30	
	Latex, latex and rubber solutions and suspensions	L40	
	Synthetic adhesive wastes	L50	
	Ion-exchange resin wastes	L60	
M Fuel, oils and greases	Mineral oils	M10	
	Kerosene and derv	M20	
	Fuel oil	M30	
	Vegetable and other oils	M40	
	Oil/water mixtures	M50	
	Fats, waxes and greases	M60	
N Fine chemicals and biocides	Pharmaceutical and cosmetic products	N10	
	Pharmaceutical products in retail containers		N11
	Pharmaceutical products in bulk and production containers	N13	
	Biocides	N20	
	Pesticides		N21
	Herbicides		N22
	Fungicides		N23
P Miscellaneous chemical waste	Organics identified by trade names[32] only		P31
	Inorganics identified by trade names[1] only		P32

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[32] Where trade names are used the source of the material should be specified

Type of Waste	Groups and sub-groups	Group code	Sub-group code
Q Filter materials, treatment sludge and contaminated rubbish	Used filter materials eg kieselguhr, carbon, filter cloths	Q10	
	Contaminated rubbish (including bags and sacks)	Q20	
	Empty used containers	Q30	
	Industrial effluent treatment sludges	Q40	
R Interceptor wastes, tars, paint, dyes and pigments	Tank cleaning sludge (note K60 for lead contents)	R10	
	Interceptor pit wastes (note M10-M30 for oil content)	R20	
	Printing industry wastes (ink manufacture and use)	R30	
	Dyestuffs waste	R40	
	Distillation residues	R50	
	Acid tars	R60	
	Tar, pitch, bitumen and asphalts	R70	
	Paint waste (manufacture and use)	R80	
Miscellaneous wastes	Tannery and fellmongers waste	S10	
	Tannery waste		S11
	Fellmongers waste		S12
	Cellulose wastes (natural and synthetic	S20	
	Waste treated timber	S30	
	Soap and detergents	S50	
	Soap		S51
	Detergents		S52
Animal and food wastes	Animal processing wastes	T10	
	Carcasses and flesh		T11
	Blood, fat, grease etc		T12
	Excrement		T13
	Food processing wastes (including starch)	T20	
	Glue wastes	T30	

Appendix F

Health and safety

Legislative background

F1. The Health and Safety at Work etc. Act 1974 imposes a general duty on employers to ensure, so far as is reasonably practical, the health, safety and welfare at work of all employees. A duty is also placed on employees to take reasonable care to ensure they do not endanger themselves or others by their work activities and to co-operate with employers and others in meeting statutory requirements. The general duty to other people rests with the employer and the self employed operator as well as the employee and includes members of the public, children, service engineers and road users. Site licensing does not affect these obligations and WRAs should not seek to control matters more properly dealt with by the Health and Safety Executive. Health and Safety aspects specific to co-disposal are considered below and any areas where it is appropriate for WRAs to apply licensing controls are highlighted.

General considerations

F2. The Act requires the landfill operator, as an employer, to issue a health and safety policy statement which clearly outlines the responsibilities of the employer, the duties of the employee and other general advice on basic safety, emergency procedures and other more specific hazards relevant to the operation of a co-disposal site. The health and safety policy should refer to more specific and detailed procedural documents such as Site Operating Procedures.

Site operating procedures

F3. For many aspects of co-disposal operations it will be necessary to prepare written Site Operating Procedures (SOPs). An SOP is a step by step description of how the task or process should be carried out, which takes into account the hazards likely to be encountered. It must detail the precautions necessary to avoid or minimise the risks to the health and safety of individuals working on those tasks or processes. It must also take account of others, such as visitors or contractors who could be affected by the activity.

F4. SOPs should take account of the employer's responsibilities with respect to the Control of Substances Hazardous to Health (COSHH) Regulations 1988. An assessment system should be in place and the information generated should be made available, when required, to those employed in handling substances, as well as those visiting or sub-contracted to work on the site.

F5. Inventories will be required and assessments performed on substances and materials entering the landfill site under the supervision of the site manager. He may be assisted in this task by staff designated and trained as 'COSHH representatives'. Each SOP should be assigned a specific Hazard/Risk code which can be used to identify appropriate Personal Protective Equipment (PPE) for the task.

F6. Some safety aspects covered by SOPs should be the subject of site licence conditions or included in the Working Plan. They should include

- staffing levels and chain of responsibility (including training)
- vehicle off-loading and disposal operations
- safety equipment and emergency procedures.

These are now discussed.

Staffing levels, chain of responsibility

F7. Minimum staffing levels to be maintained for particular operations should be specified and the chain of responsibility clearly indicated. Because potentially hazardous materials are being handled, the number and calibre of staff are likely to have to be higher than for an equivalent-sized landfill receiving only non-hazardous wastes. Some sites have specialized teams dealing only with co-disposal and most major sites employ technical staff on site. The site licence should state whether a chemist is expected to be on-site at all times when special wastes are being received, processed or deposited and the level of qualification required. This will depend upon the size of the operation and the range of special wastes. Site chemists usually have a degree, HNC or equivalent qualification.

Training

F8. The operator must demonstrate that hazards connected with the site operations have been evaluated and communicated to all site staff. This must be backed up with training and adequate supervision. For many operational staff, special training may be needed in first aid techniques and the use of breathing apparatus. Additional training may be needed for clerical staff dealing with the Technical Control documentation and with the keeping of records of special waste inputs. Traffic control, supervision, and marshalling of the disposal operations themselves, are normally carried out by operatives who have received training in safety, first aid, the use of breathing apparatus and often have attended specialised courses on landfill and hazardous waste management.

Vehicle off-loading and disposal operations

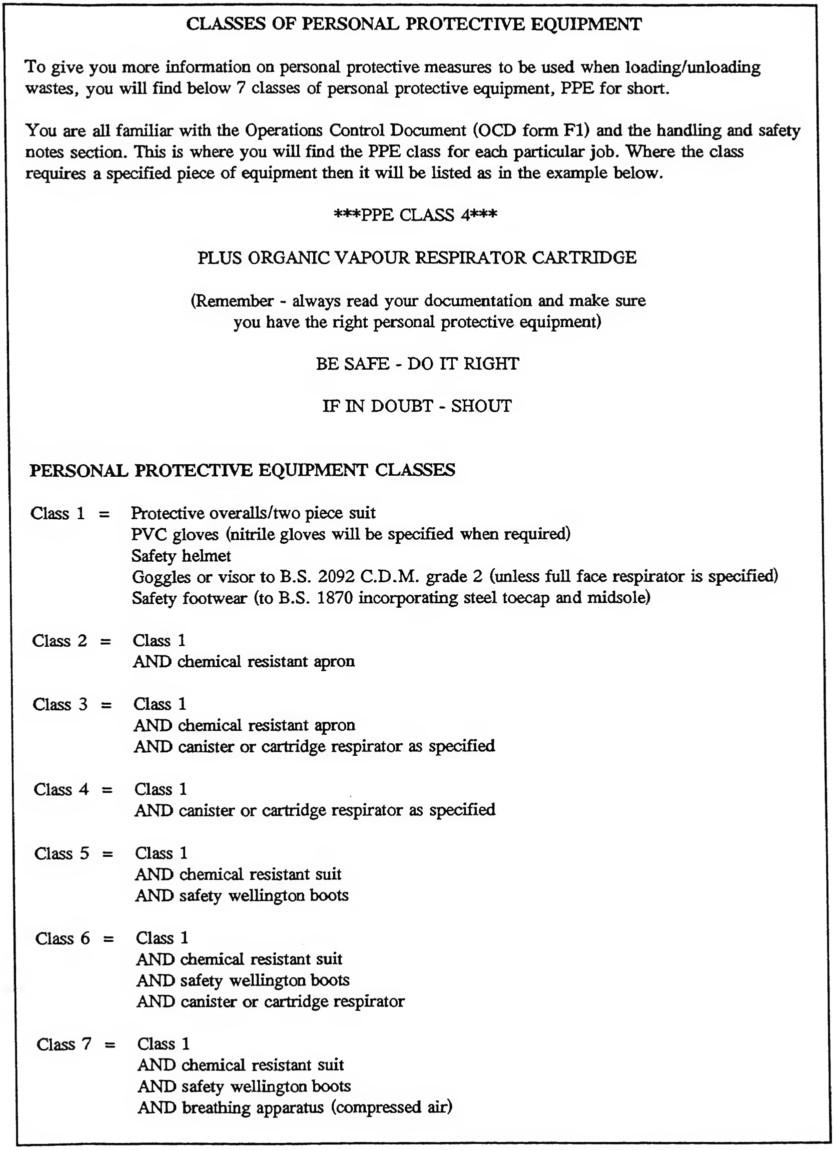
F9. In some cases it will be necessary for a qualified chemist to be present on site for waste inspection, sampling and testing and for supervision of vehicle off-loading and waste emplacement. Such supervision is often backed up by ratio contact with a site control centre throughout the off-loading procedure. Precautions taken to prevent accidents during the handling of special wastes at a co-disposal site vary but are generally similar to those used at any facility for the treatment or disposal of special wastes. For instance, physical safeguards during the discharge of wastes to trenches should include the placing of fencing, bunds and warning signs all around the trenches. Wind socks, emergency showers and first aid equipment should also be provided, details of which should be provided by the operator in SOPs and the Working Plan.

Safety equipment and emergency procedures

F10. The WRA should specify safety equipment and Personal Protective Equipment (PPE) to be maintained. These should be appropriate to the degree of risk but may include fire-fighting equipment, first aid equipment, first aid station, and a range of personal protection equipment. The use of an easy reference pocket 'safety' card is a good way of providing instant practical information on the appropriate PPE for different classes of activity on a co-disposal landfill site. An example is shown in Figure 11.1.

F11. Emergency procedures in the case of fire or accident should be established and should be familiar to all site staff. Where appropriate these should be reinforced with practice drills. Regular liaison on emergency procedures should be held between the management and representatives of fire, ambulance and local hospital services.

Figure F.1 Classes of Personal Protective Equipment
[after Cleanaway - SUBJECT TO PERMISSION FOR PUBLISHED USE]



CLASSES OF PERSONAL PROTECTIVE EQUIPMENT

To give you more information on personal protective measures to be used when loading/unloading wastes, you will find below 7 classes of personal protective equipment, PPE for short.

You are all familiar with the Operations Control Document (OCD form F1) and the handling and safety notes section. This is where you will find the PPE class for each particular job. Where the class requires a specified piece of equipment then it will be listed as in the example below.

PPE CLASS 4

PLUS ORGANIC VAPOUR RESPIRATOR CARTRIDGE

(Remember - always read your documentation and make sure you have the right personal protective equipment)

BE SAFE - DO IT RIGHT

IF IN DOUBT - SHOUT

PERSONAL PROTECTIVE EQUIPMENT CLASSES

Class 1 = Protective overalls/two piece suit
PVC gloves (nitrile gloves will be specified when required)
Safety helmet
Goggles or visor to B.S. 2092 C.D.M. grade 2 (unless full face respirator is specified)
Safety footwear (to B.S. 1870 incorporating steel toecap and midsole)

Class 2 = Class 1
AND chemical resistant apron

Class 3 = Class 1
AND chemical resistant apron
AND canister or cartridge respirator as specified

Class 4 = Class 1
AND canister or cartridge respirator as specified

Class 5 = Class 1
AND chemical resistant suit
AND safety wellington boots

Class 6 = Class 1
AND chemical resistant suit
AND safety wellington boots
AND canister or cartridge respirator

Class 7 = Class 1
AND chemical resistant suit
AND safety wellington boots
AND breathing apparatus (compressed air)

Duties to persons other than employees

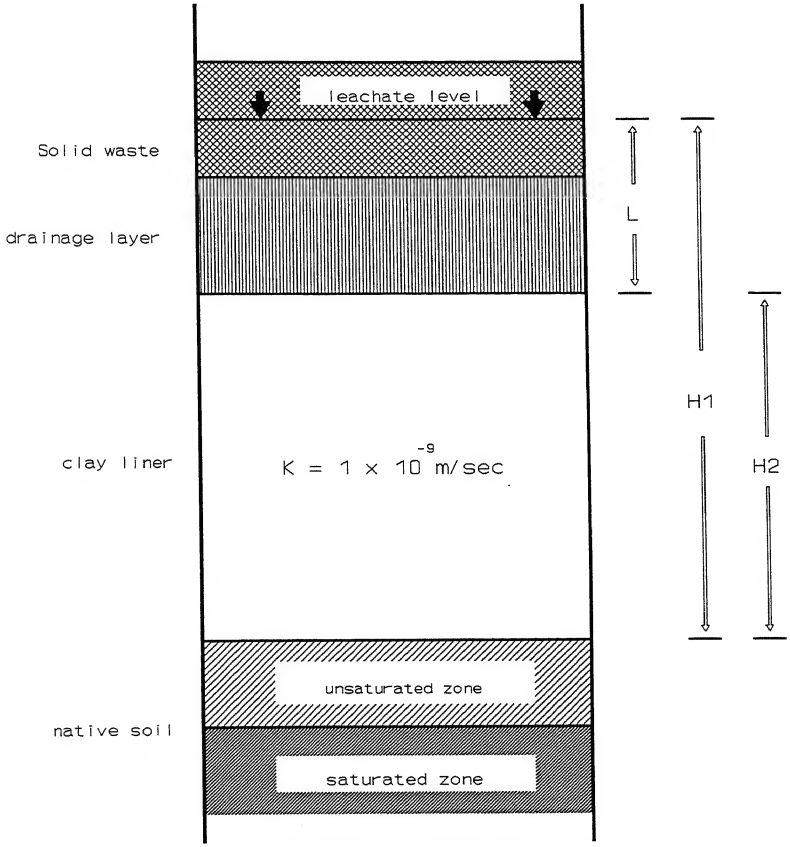
F12. Operators will be required to demonstrate special precautions for minimising risk to the general public.

Duties of waste producers/disposers

F13. In addition to Health and Safety legislation, all who produce, carry or manage waste must comply with waste management legislation, including the Duty of Care provisions of the EPAct.

F14. Accurate information must be provided on special waste consignment notes and Duty of Care transfer notes. It should include ntrol Document details of any special precautions to be observed during the collection and disposal of the waste. TCDs will also contain this information (see paragraph 6.5, 6.10).

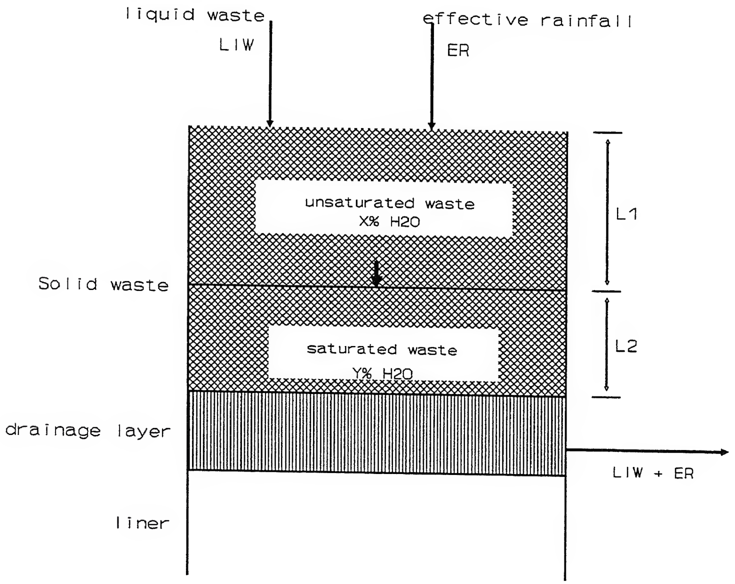
APPENDIX G
Calculation of flow through clay liner and hydraulic retention time



$Q = K.I.A$ where,

Q = flow
K = hydraulic conductivity
I = hydraulic gradient (H1/H2)
A = cross-sectional area of flow

FLOW THROUGH A POROUS CLAY LINER



HRT = M/(LIW + ER) where

HRT = hydraulic retention time
LIW = liquid waste input
ER = effective rainfall input

and

M = (L1.A.X)/100 + (L2.A.Y)/100 where

M = total moisture content in reaction zone
L1 = unsaturated depth
L2 = saturated depth
A = area of reaction zone
X = % moisture content in unsaturated zone
Y = % moisture content in saturated zone

CALCULATION OF HYDRAULIC RETENTION TIME IN REACTION ZONE

GLOSSARY

ABSORPTIVE CAPACITY The amount of liquid which may be taken up and retained against the pull of gravity, by unit weight of solid material, under specified conditions; usually the amount of water retained by wastes in a landfill before leachate is produced.

ACETOGENIC PHASE The initial period during the decomposition of refuse in a landfill, when the conversion of organic polymers, such as cellulose, to simple compounds such as acetic and other short-chain fatty acids dominates, and little or no methanogenic activity takes place.

ADSORPTION The uptake and retention of one substance on to the surface of another.

AEROBIC PROCESS A bacterial process which requires the presence of molecular oxygen.

ANAEROBIC BIOASSAY TEST (ABT) A test using live anaerobic bacteria to assess the fate and impact of a chemical or a waste, by measuring inhibition of methane production and any attenuation of the chemical or waste, during incubation under specified conditions.

ANAEROBIC PROCESS A process performed by bacteria which require the complete absence of molecular oxygen. Such bacteria are in fact poisoned by the presence of oxygen.

ANOXIC PROCESS A bacterial process similar to aerobic processes, often performed by some of the same bacteria, but which can take place in the absence of free oxygen, using other substances, such as nitrate or sulphate, as a source of oxygen.

AOX A blanket term for organohalogen compounds which are readily adsorbed onto activated carbon. It is used as a control parameter in some countries but many simple halogenated hydrocarbons do not adsorb efficiently during the test and its usefulness in leachate characterization remains questionable.

AROMATIC Term used to describe any organic compound containing one or more benzene rings.

ATTENUATION A decrease in concentration caused by any of a variety of mechanisms, individually or in combination, including dilution, adsorption, precipitation, ion-exchange, biodegradation, oxidation, reduction, etc.

BED VOLUME The total moisture content of the wastes in a particular landfill or container, including free leachate and any absorbed moisture. The bed volume and the rate of inflow of rain or groundwater determine the average hydraulic retention time of water in the landfill.

BIOMASS Term used to refer to the mass of biologically active material contained in a reactor, such as a landfill or a biological effluent treatment plant.

BIOREACTIVE WASTES Wastes which have a natural tendency to undergo biological degradation and which, in co-disposal landfills, contribute to the capacity of the landfill to degrade or otherwise attenuate components of co-disposed industrial wastes.

BUFFERING CAPACITY A measure of the ability of waste to neutralize acid or alkaline wastes added to it.

DENITRIFICATION see Nitrification.

EFFECTIVE RAINFALL Total rainfall minus actual losses due to evaporation and transpiration. Effective rainfall includes both surface run-off and that which percolates into the ground below the soil zone.

Eh A measure of the oxidising or reducing potential of a system, usually expressed as a voltage, relative to a standard hydrogen electrode. Also known as redox potential. Low Eh indicates reducing conditions and high Eh indicates oxidising conditions.

FERMENTATION A type of anaerobic process in which organic compounds are completely degraded to methane and carbon dioxide.

FLASHPOINT The lowest temperature at which a material will provide sufficient vapour to 'flash' or burn momentarily when an ignition source is applied under specified conditions.

HYDRAULIC RETENTION TIME (HRT) The total moisture content of the wastes in a particular landfill or portion of landfill, divided by the rate at which water passes into, and out of, that portion of landfill.

LIGAND A substance, usually organic, which can form bonds with metal ions in aqueous solution, resulting in chemical species called complexes, whose behaviour may differ from that of the free metal ion.

LANDFILL LOADING POTENTIAL The rate at which an organic compound may be degraded in a co-disposal landfill under ideal conditions, usually expressed as mass of compound per unit volume of landfill within a specified period.

METHANOGENIC PHASE The period during the decomposition of refuse when a dynamic equilibrium has become established between the bacterial production of simple compounds such as fatty acids, and their conversion by other bacteria to methane and carbon dioxide (landfill gas). Typically, several years may elapse before the methanogenic phase is reached.

MUNICIPAL WASTE as defined in the draft Landfill Directive, means domestic refuse, as well as commercial or trade refuse and other waste which, because of its nature or composition, is similar to domestic refuse.

NITRIFICATION/DENITRIFICATION Nitrification is an aerobic bacterial process in which ammonia is converted to nitrate. Denitrification is an anoxic bacterial process in which nitrate is converted to nitrogen gas.

REACTION ZONE That portion of a landfill with which liquid waste or leachate from co-disposed solid waste will come into contact before leaving the site for treatment or disposal.

SINGLE PASS MODE A mode of operation in a SFFR in which influent passes just once through the reactor, either vertically or horizontally. Multiple pass mode may be achieved by recirculating the effluent through the reactor several times the net rate of inflow. This is often used in SFFRs and can produce more efficient treatment than a single pass.

SPECIATION The distribution of a substance, such as a heavy metal, among different chemical forms or species. For instance when a salt of a heavy metal is dissolved in water, the heavy metal itself may be distributed among several different forms as a free ion and as complexes, depending on the pH and the presence of organic ligands.

STATIONARY FIXED-FILM REACTOR (SFFR) A type of reactor in which the reactive medium is the surface of a solid phase which remains stationary, while the wastewater moves through it. An example is a percolating filter used for sewage treatment.